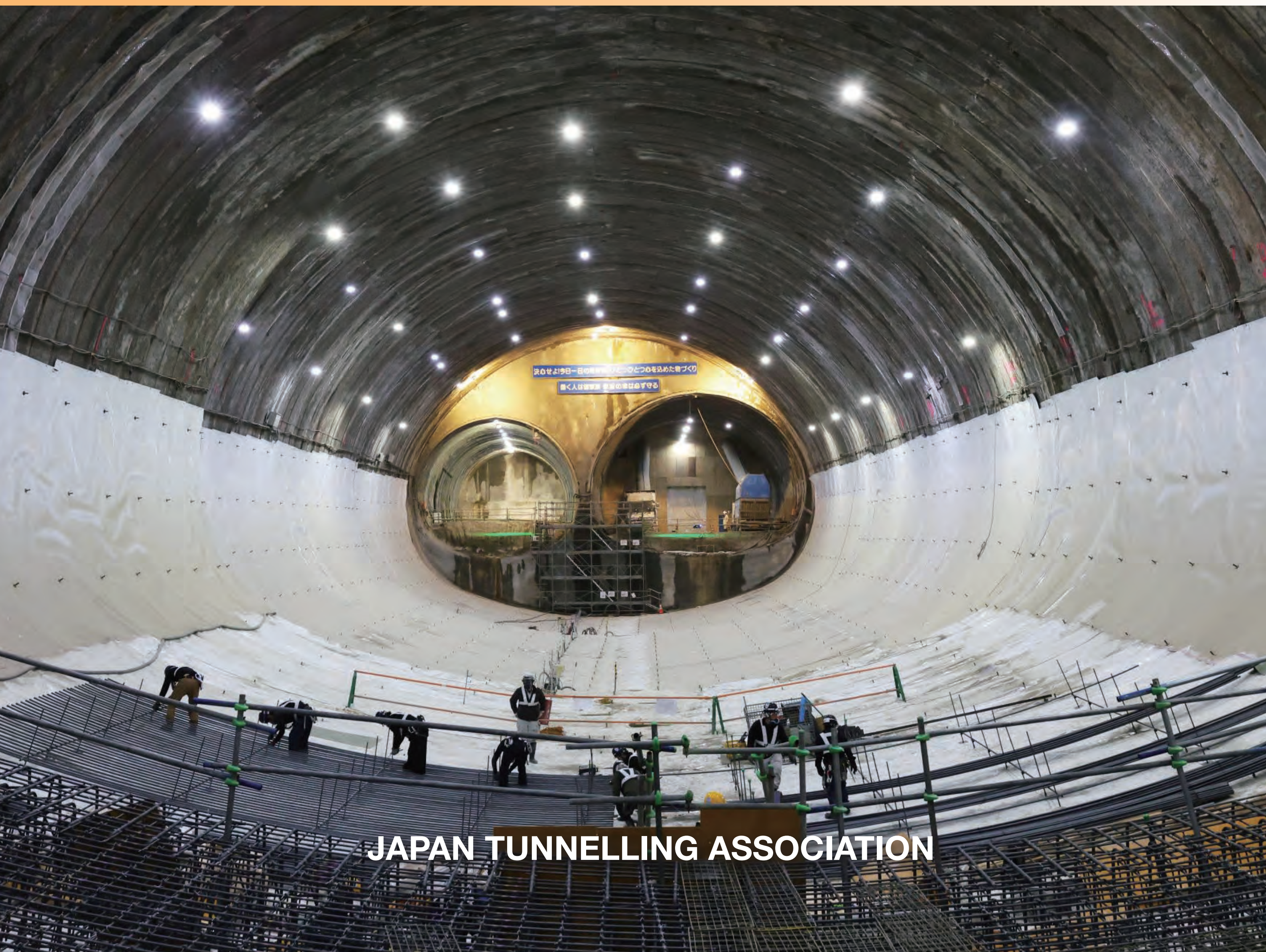
Challenges & Changes

TUNNELLING ACTIVITIES IN JAPAN 2024



JAPAN TUNNELLING ASSOCIATION

PREFACE

I feel really privileged to be given this opportunity to address tunnel engineers throughout the world on the occasion of the publishing of the 2024 edition of Tunnelling Activities in Japan, Japan Tunnelling Association (JTA)'s biennial publication. The number of tunnel construction projects in Japan is still high, as various technical challenges being overcome for Shinkansen, expressways, and water and sewage projects.
Technology tried and proven during such domestic projects are utilized overseas, and Japan remains as one of the leaders of global tunneling technology.
Increase in tunnel length and expansion of tunnel cross section are two specific features in mountain tunnels of recent tunnel projects in Japan. The advancement in tunnel design and tunneling technologies in resent years has made it possible to construct long tunnels and large section tunnels safety and economically, even under the complex and wide-ranging ground conditions in Japan. As a result, it has become possible to choose the shortest routes and higher standards in railway and road projects.
In construction of urban tunnels, there are many cases in which construction works is implemented in the proximity of existing structures in areas where there is a convergence of underground structures such as subways, utility lines, etc. In addition, urban tunnels, being built in soft ground and needs due consideration to living conditions of the surrounding houses, must be constructed to meet strict demands for reducing the impact on the surrounding environment. These factors have fueled the progress in the development of design and construction methods and shield machines that can fulfil the specific requirements for construction of urban tunnels.
In addition, in recent years, Japanese tunnel technology has been making use of new technologies such as ICT-based measurement systems, AI and robotics. Based on such recent specific examples, this booklet presents a selection of some typical examples representative of the numerous tunnel projects and technological developments in Japan. I will be pleased if these articles prove useful for tunnel engineers around the world.

KIKUKAWA SHIGERU

President
Japan Tunnelling Association

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Innovations in Technology

Tunnel Activity 2024 Overview

1. preface

Desires for new tunneling for rails, roads, water supply and sewages, etc. are still robust in Japan while the number of tunneling engineers has been decreased due to the shrinking economy and population. While these new tunnels must be constructed at technically challenging places in complexed geology of the Japanese Archipelago, existing tunnels which had been constructed during the era of Japan's miraculous economic development after the second world war are over fifty years old and require drastic repair works, hence various innovative tunneling techniques have been introduced in both fields of excavation and maintenance. We Japan Tunneling Association so called JTA has published leaflets of the Tunnel Activities in Japan in every two years which contain then state-of-the-art tunneling technologies. This new publication also introduces ongoing tunneling projects and newly developed tunneling techniques to overcome social and technical hurdles confronting us Japanese tunneling experts. At the end of the leaflet, you can refer the contact list to reach further information of these new projects and techniques. It is a great pleasure of ours if this leaflet can be useful in the progress of your tunneling projects in the world.

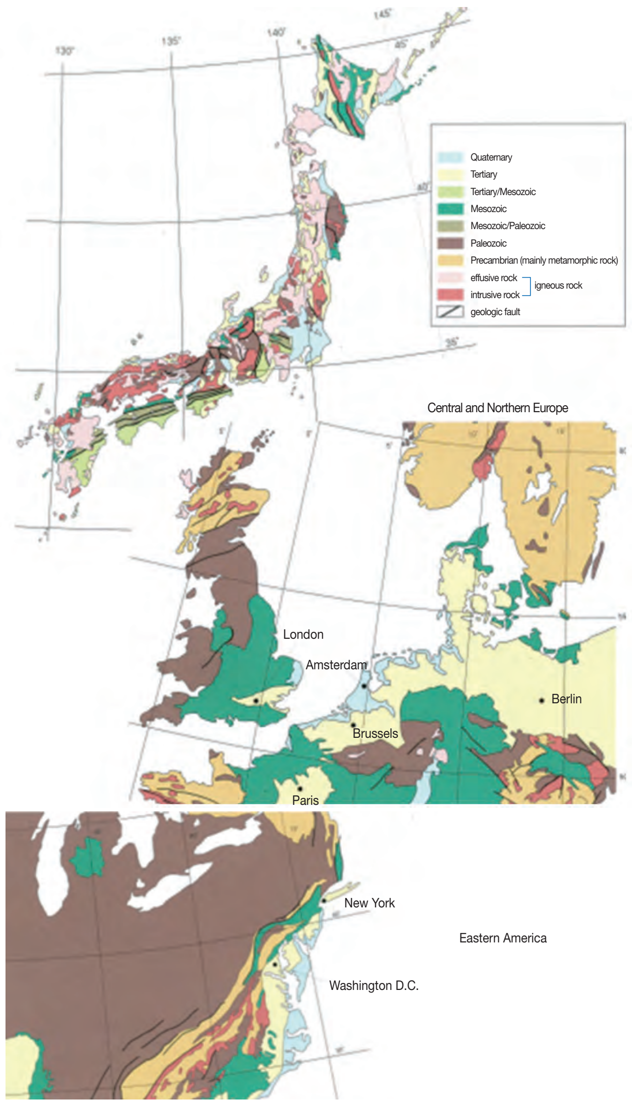

Fig.-2.1 Differences of Geology of Japan and the Western world

Photo-2.1 A Tunnel Face Sample in Japan with Soft and Hard Ground

2. Complicated geological condition in Japan

The Japanese Archipelago consists of small mountainous islands of total 380,000 square kilometers in area and locates at the fringe of the circum-Pacific Volcanic Belt. Thus, 70% of our land belong to mountain zone and population of more than 12 million must be concentrated in scarce flat inhabitable area. And most of the inhabitable area have been already developed and hard to find extra space on the ground. This is the reason why underground developments have been aggressively progressed in Japan. Additionally, because these inhabitable urbanized regions are dispersed through the land and divided by the mountainous zones, tunnels as connection infrastructure have had a vital role for the national development.

On the other hand, those mountainous conditions have been making our tunneling excessively daunting. As mentioned above, our archipelago locates at the fringe of the circum- Pacific Volcanic Belt where the Pacific Plate and the Philippine Plate conflict which makes the geology complicatedly disturbed. Photo-2.1 shows an example of tunnel face, where various types of rock can be observed. The plains of major urban areas consist of deposits in newer geological eras, causing the soft ground. Despite such a challenging situation, underground of the urban areas had been excavated and densely utilized as infrastructure such as subway, water supply and sewage. It is extremely difficult to find out enough margin to add new underground infrastructure in this situation and soft geology has been worsening the tunneling condition. It can be said that these hardships surrounding tunneling have made our tunneling technology greatly advanced.

3. Recent topics new

Numerous underground infrastructures have been built in Japan and steady investment is made to maintain and grow the domestic economy, as well as creating safe and secure land(Fig.-3.1). After peaking in 1995, the investment in tunnels and underground space decreased slowly year by year, since the government restrained the public investment. Recent years see the increase of the investment after 2014 due to the reconstruction following the Great East Earthquake in 2011. Fig.-3.2 and 3.3 shows the trend of construction investment in tunnels and underground space by type. Mountain tunnels

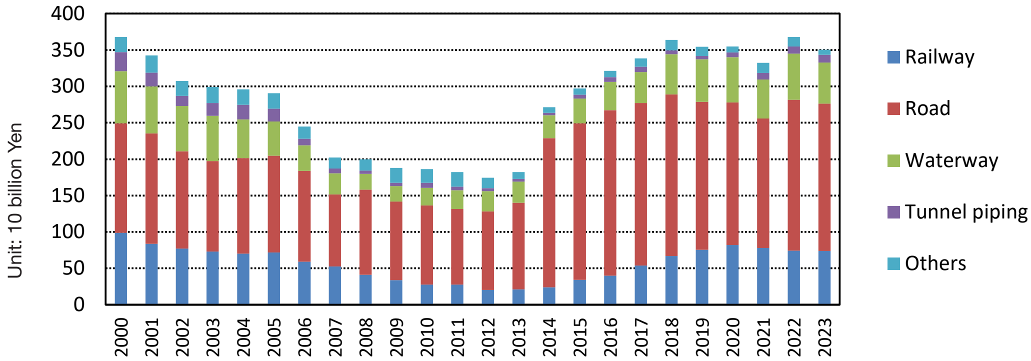

Fig.-3.1 Trend of construction investment in tunnels and underground space

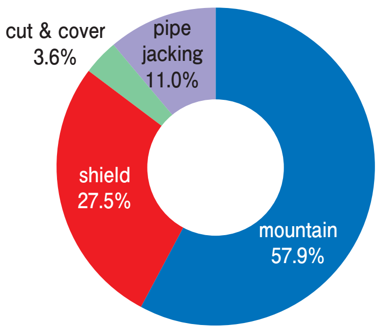

Fig.-3.2 Ratio by Tunnel Construction Method

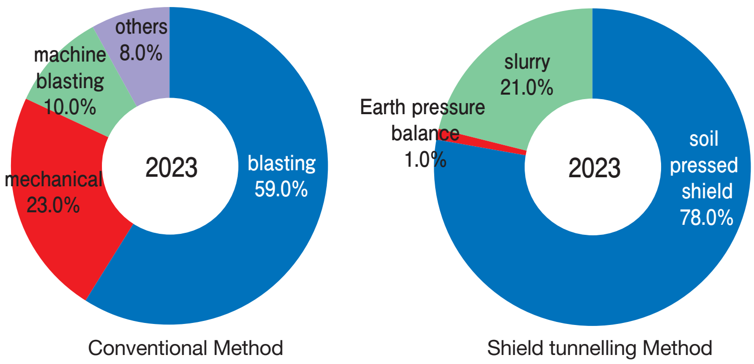

Fig.-3.3 Ratio of Tunnel Construction by Method

are 57.9%, with 59% of that using blasting. Shield tunnels consist of 27.5% of all constructions, and 78% of that use soil-pressed shield method.

In terms of the technical development, forepiling and facebolting have been widely used to stabilize the tunnel face nowadays. In addition, double-layered support has been adopted to restrain the ground displacement in the highly squeezing ground. The latest trend of research and development is remote/automatic tunnel construction to improve the productivity as the number of skilled tunnel workers has been decreasing.

4. Recent topics maintenance

Most of tunnels in Japan had been constructed during the high economic growth after the second world war and are over fifty years old, hence maintenance and repairing of those tunnels are urgent issue.Current situation of road tunnels and railway tunnels are as follows:

Road Tunnels: As of 2023, there are approximately 11,000 tunnels with a total length of 5,100km built for road tunnels(Fig.-4.1). The Road Law revised in 2014 has required all road tunnels to be visually inspected onsite and diagnosed at least once in five years. The deformations of tunnels should be appropriately repaired based on the result of the diagnoses.

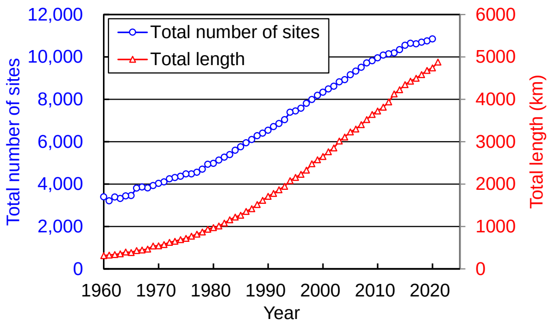

Fig.-4.1 Number and Length of Road Tunnels in Japan

Railway Tunnels: As of 2021, the total length of railways owned by the seven JR group companies(former national railway) has become 19,675.60km. There are 3,482 tunnels, consisting 2,419 km of that distance(*) The ratio of tunnels more than 50 years old is almost 60%. There are directions by the Ministry of Land, Infrastructure, Transport and Tourism(MLIT) determining the technical standards of railways, and these directions state the frequency of inspections. Regular inspections(Standard General Inspection) must be held within two years. In-depth inspection(Special General Inspection)must be held within 10 years for Shinkansen high speed rail and within 20 years for other railway tunnels in addition to regular inspections.

*Annual Railways Statics Report(2022), MLIT

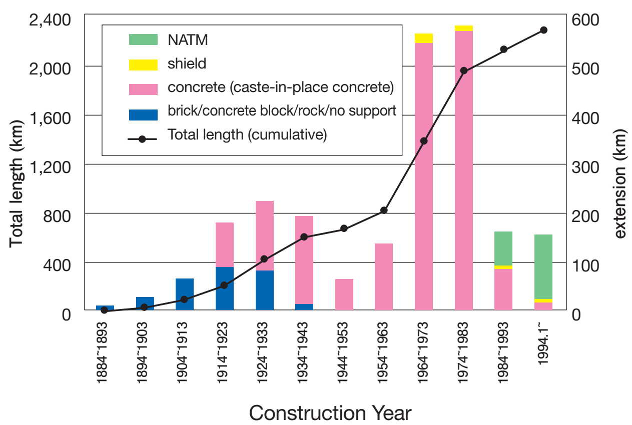

Fig.-4.2 Number of tunnels constructed by the seven JR companies (former national railway) by year (as of 2002)
Source:"Tunnel Library 14 Tunnel Maintenance in Japan", Japan Society of Civil Engineers, July 2005

Construction of a Subway within a Short Period by Overcoming Underground Obstacles in Soft Reclaimed Land

— Infrastructure Maintenance Work of the Hokko Techno-Port Line —

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Toshiki KAWADA ▶ General Manager, Yumeshima Extension Line JV Construction Office, Obayashi Corporation

1. Features of This Construction Work

This work comprises the construction of a shield tunnel section (760 m, two single-track shields) from the Yumesaki Tunnel section to the Yumeshima South Track section, as well as cut-and-cover tunnel sections (190 m for the South Track section and 190 m for the Station section) at the Yumeshima South Track section and Yumeshima Station on the Hokko Techno-Port Line between Cosmosquare and Yumeshima stations (Figure-1).
In addition to the technical challenges unique to reclaimed land, this project had a short project period of approximately five years from design to the start of business. Early Contractor Involvement method, in which technical cooperation is provided by the builder from the design stage, was adopted to start construction at an early stage and prevent rework due to design changes during construction. The construction is proceeding at a rapid pace, with the aim of opening the in FY2024, the year before the Osaka–Kansai Expo 2025 is scheduled to be held.

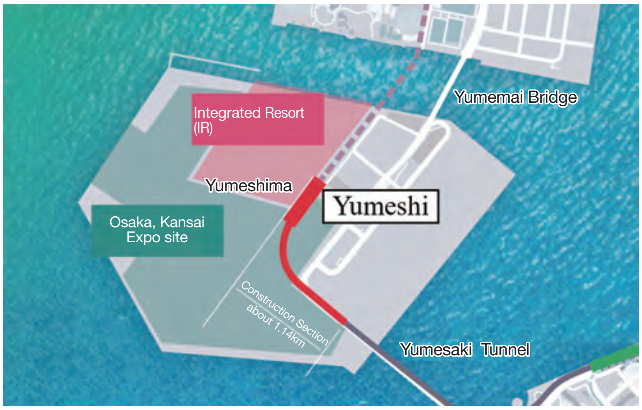

Fig. 1 Construction location map

2. PBD Cutting by Extrusion Cutter

Plastic board drains (PBDs) were buried along the entire shield tunnel section. Initially, it was planned to use a rotary cutter; however, the cutter would be subject to severe wear and may require replacement, thereby affecting the process. Therefore, a newly developed extrusion-type cutter was adopted (Figure-2). This technology has the advantage that the PBD to be buried in the next ring drilling range can be cut in advance during segment assembly by simply pushing out the cutter bit for a length equivalent to the segment width. This results in less wear on the cutter, facilitating reliable cutting without affecting the process (Figure-3).

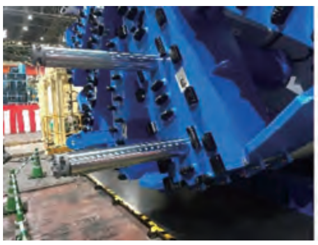

Fig. 2 Extrusion cutter bit

Fig. 3 PBD cut piece

3. Rational Basis for Temporary Structures and Construction

Diagonal struts are generally used to reduce the design span of the retaining wall, but they require several members to be attached and take time to erect. Furthermore, they interfere with the excavation work directly under the retaining wall, the loading and unloading of materials and equipment, and the construction of the structure. Therefore, the "hammer strut" was applied to the cut-and-covert tunnel section as an alternative structure to help remedy the above issues. This method, installation of H-section steel parallel to waling strip at connecting part of strut and waling strip, eases the installation process, and it can be composed of highly versatile members (Figure-4).

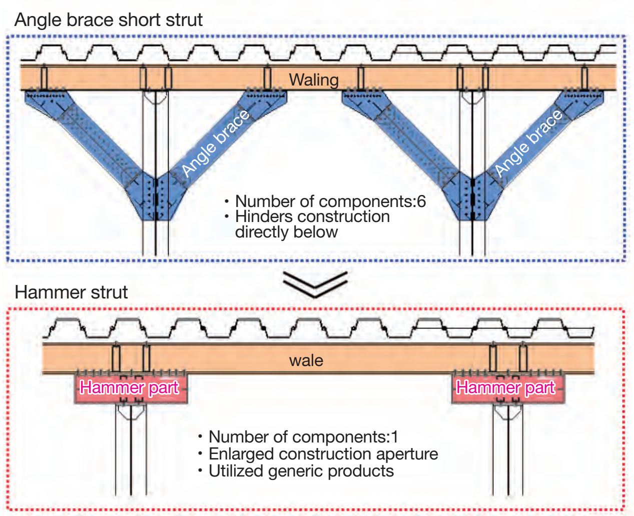

Fig. 4 Hammer strut structural drawing (plan view)

Photo 1 Application of the system on site

The subway tunnel was constructed within a short project period on reclaimed land through the introduction of the aforementioned new technologies.

2

Results of Tunnel Construction in Swelling Grounds

— Hokkaido Shinkansen, Tateiwa Tunnel (Tateiwa), etc. —

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1. Introduction

The Hokkaido Shinkansen is a line connecting from Aomori City to Sapporo City, and the 211.9 km-long section between Shin-Hakodate-Hokuto Station and Sapporo Station is currently under construction. Tateiwa Tunnel, with a total length of 17,040 m, is located between Shin-Yakumo Station (tentative name) and Oshamambe Station of the Hokkaido Shinkansen line currently under construction. The construction area of Tateiwa Tunnel (Tateiwa), etc. falls under the area to be constructed for 5,015 m from the portal opening on the starting point side. (Figure-1)

2. Characteristics of the Tunnel / Countermeasures

1) Geological conditions

Concerning the geological conditions, the assumed distribution is as follows: andesite tuff breccia (LMt) for approx. 400m from the portal opening; basaltic pyroclastic rock (LMb) for the following approx. 1,200 meters; mixture of shale, tuffaceous breccia, and green tuff (LM LMt) for 1,600 m after that; and basaltic pyroclastic rock (LMb) for the subsequent area. (Figure -2)
Also, according to the existing geological surveys, a swelling ground containing a large amount of smectite has been assumed from around the 208-km and 600-m point from Shin-Aomori. In the actual construction, the condition includes a ground with the smectite content of 39% from the 207-km and 411-m point, with the competence factor of around 2, with the moisture content of 2 ~ 10%, and with the overburden of over 200 m, which makes a swelling ground where earth pressure is likely to occur. Thus, there has been a concern over an increase in the inner space displacement and heaving.

2) Countermeasures

As a countermeasure to restrain inner space displacement in a swelling ground, the support pattern is established by the competence factor and the elastic wave velocity and it is changed according to the face condition and the result of inner space displacement measurements. Furthermore, reinforcement works have been implemented as needed according to the inner space displacement measurements. Since these stepwise countermeasures according to the measurement results affect the progress of construction works, selecting of an appropriate support pattern in an early stage has become one issue to ensure more efficient execution of works. (Figure-3) Therefore, by focusing on the relation of the final displacement amount to the competence factor and the initial displacement amount for each support pattern, we have formularized a prediction expression to estimate the final displacement amount by using the inner space displacement in 24 hours after the start of measurement as the initial displacement, and the competence factor, and the smectite content.
As a result, we have obtained a high correlation with the actual final displacement amount and confirmed the validity of each support pattern in an early stage of displacement. (Figure-4)
Also, as works to prevent heaving were implemented even after the completion of construction for some sections already in service, countermeasures in the construction stage are necessary. Accordingly, we have selected inverted shapes according to the ground sample test indicators (such as the competence factor and the smectite content) in an advanced survey boring.

3. Knowledge and Results Obtained

By selecting the support pattern by utilizing the prediction expression, the final displacement amount has been kept under the control standard value. By identifying the initial and final displacements including the inner space displacement and the crown settlement, and further by appropriately predicting the final displacement amount according to the prediction expression, we have been able to implement the effective construction method. We will further improve the accuracy of prediction expression by utilizing the measurement results of other swelling grounds.
As a result of selection of inverted shapes based on the ground sample testing indicators, there is no heaving phenomenon at present and we consider that appropriate selection has been made.

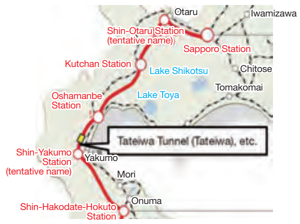


Fig. 1 Construction area map

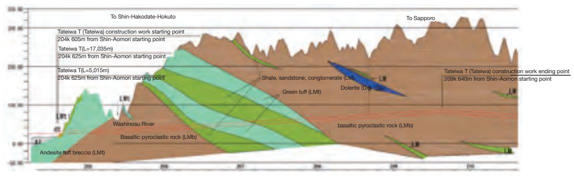


Fig. 2 Geologic cross section of Tateiwa Tunnel (Tateiwa) and other construction sections

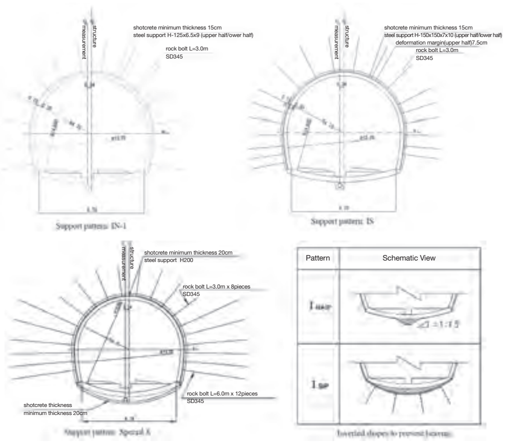


Fig. 3 Support patterns and inverted patterns

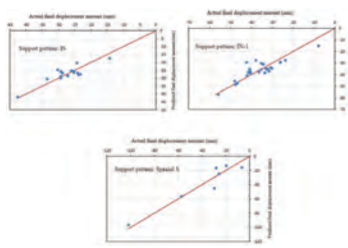
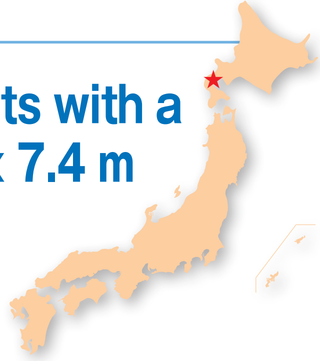


Fig. 4 Relation between the actual final displacement amount and the predicted final displacement amount for each support pattern

Construction of a Mountain Tunnel which Intersects with a Highway, with the Minimum Overburden of Approx 7.4 m

— Hokkaido Shinkansen, Kunnui Tunnel —



Seigo YONEKURA ▸ Staff, Oshamambe Construction Site Office, Hokkaido Shinkansen Construction Bureau, Japan Railway Construction, Transport and Technology Agency (JRTT)

1. Introduction

The Hokkaido Shinkansen is a line connecting from Aomori City to Sapporo City, and the 211.9 km-long section between Shin-Hakodate-Hokuto Station and Sapporo Station is currently under construction. Kunnui Tunnel, a mountain tunnel with the total length of 1340 m, is located between Shin-Yakumo Station (tentative name) and Oshamambe Station, after the start of tunneling by NATM in December 2020, it was completed in October 2022.

2. Characteristics of the Tunnel / Plans

This tunnel is characterized by the intersection with a highway in service, with the minimum overburden of 7.4 m (Figure-1). According to the assumed distribution of low-consolidated layers mainly of conglomerate, sand and clay in the highway intersection part, it was estimated that excavating of these layers might cause surface settlement or collapse of the highway over the ground and that this would make tunnel excavation a very difficult work.
To ensure safe excavation directly below the highway in service, we have predicted displacement of the Shinkansen tunnel and the highway during excavation by a numerical analysis (FEM) in advance and decided the excavation method with reference to the results of similar construction works. Although we have examined an open cut method and a shield method as well in view of the geological features and overburden, we have adopted a plan of excavation by the NATM taking account of the on-site conditions, the construction period and the economic performance. We have preliminarily implemented a test construction in a section with a similar geological features and overburden in this construction area to confirm the safety of excavation by the NATM, and we have established the construction method for the highway intersection part by analyzing and evaluating the results obtained from the test construction.
Also, for the measurements during the excavation of highway intersection part, monitoring of the ground surface settlement has been implemented by using a ground-mounted measuring instrument, in addition to a common displacement measurement inside the tunnel. Upon consultation with the highway administrator, we have established three-stage control standard values concerning the ground surface settlement to implement measures according to each stage; we have decided to stop excavating in an event of settlement identified as the control level III which affects running vehicles; and thus, we have developed a structure to secure the safety of regular vehicles running on the highway.

3. Results of Construction

In the test construction, the displacement occurred was larger than that predicted in the analysis and the amount of ground surface settlement reached the control level III in the highway intersection part. The estimated causes are as follows: the ground of the construction section concerned has a distribution of unconsolidated sandy gravel layer which is thicker than we predicted; the earth bearing capacity of the upper-half root foot part is insufficient; and the rigidity of support is insufficient.
Accordingly, to minimize the ground surface settlement in the construction for the highway intersection part, we have decided to implement additional measures (Figure-2) such as reinforcing of legs, connecting of front and back supports, and shortening of cycle until the primary cross-section closure.
We have observed weakly consolidated silty sand on the whole surface of the cutting face of the highway intersection part; however, the ground surface settlement was restrained to within the control level I (Figure-3) even in the place with the largest settlement. Until the completion of lining work of highway intersection part in July 2023, progress of displacement has not been observed. We will continue to execute the remaining work safely with attention given to the surrounding environment.

Fig. 1 Location plan of Kunnui Tunnel

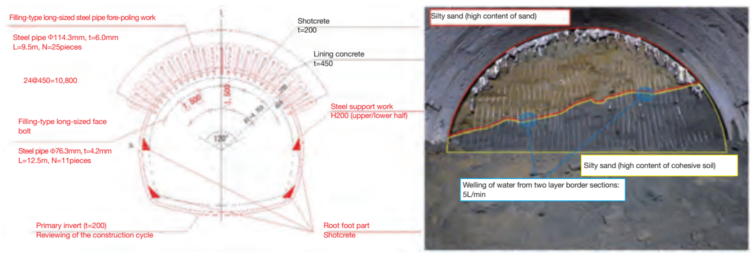


Fig. 2 Support conditions in the highway intersection part

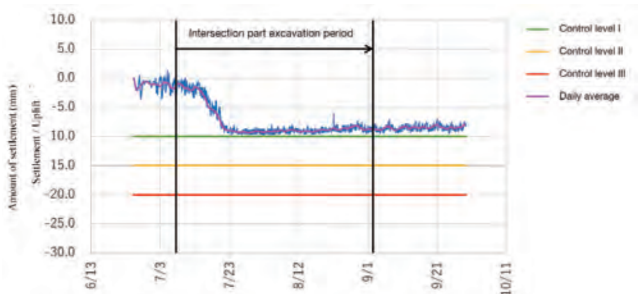


Fig. 3 Results of measurement of point with the largest ground surface settlement

Train Car Yard Plan for Minatomirai Directly under Harbor View Park

Kazuyuki TAKAGI / Yuta IMATOMI
▶ Project Development Office, YOKOHAMA MINATOMIRAI RAILWAY COMPANY:
Daisuke ONOZUKA / Yusuke MATSUZAKI
▶ KAJIMA CORPORATION, TOA CORPORATION and Nara Construction Co,Ltd, Joint ventwre

1. Outline

This construction project is to build, at a site beyond the terminal station of the Minatomirai 21 Line, a railway facility (train car yard) by a mountain tunneling method for placing train cars owned by Yokohama Minatomirai Railway Company.
As shown in Figure-1, the train car yard is 590m tunnel consisting of three cross-sections of a single line, a double line, and a parallel line. The single line section is a glasses-shaped twin tunnel, which can accommodate single train car, connected to the terminal station. The double line section has a large cross-section as rails are laid for trains to intersect. The parallel section is a glasses-shaped twin tunnel serves as train car yards, each of them can accommodate two train cars. There is a rugged tourist area, surrounded by residential area with 20m-30m earth covering, directly above the train car yards. Therefore, this tunnel construction by mountain tunneling method is conducted under very restrictive conditions.

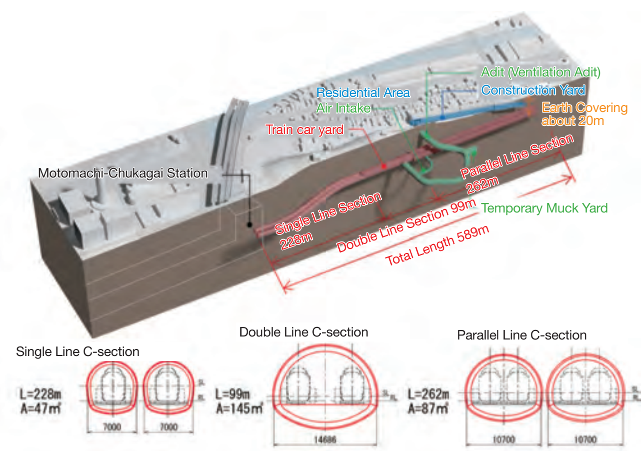


Fig. 1 Perspective Drawing of Train Car Yard

2. Ordering Method for This Construction Project

This construction project required a detailed design that would not delay the start of service in 2030 and would allow construction of train car yards within the project budget. Therefore, an ordering method (ECI method) was adopted to reflect the advanced technology and opinions of the constructor in the detailed design. In the ordering method generally practiced in Japan, the project owner conducts the survey and design through the designer, the constructor determines the costs and receives the construction order. In the ECI method, on the other hand, the owner contracts with the constructor from the design stage, and the contract is awarded to the constructor when both parties agree on the amount of construction work based on the design reflecting the constructor's knowledge and technology. In this project, the ECI method was adopted because there was not enough time to investigate the construction conditions and to design the structural form, etc., and it was necessary to aim for early launch of operation of the train car yards. The conceptual diagram of the process is shown in Figure-2.

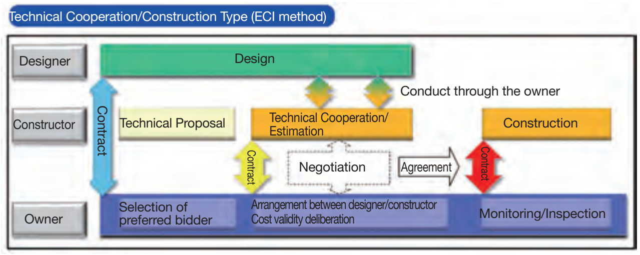


Fig. 2 Conceptual Diagram of Technical Cooperation and Construction Type (ECI Method)

3. Detailed Design by ECI Method

The following are major case examples in which, by the ECI method, the contractor changed the design from the basic design in terms of economy, shortening of construction period, impact on the surrounding environment, and other factors.
The parallel cross-section was planned as a glasses-shaped twin tunnel with a center shaft in which a center pillar is constructed after excavating the center shaft was excavated, but as shown in Figure-3, the construction period and construction cost were reduced by changing to close-set parallel tunnels without a center pillar.
Also, in the initial plan, as a path to connect to the train car yard during the construction, a circular shaft and an adit were included. However, since it requires earth retaining and excavation of construction yard in the vicinity of residential area, it was considered that the impact on surrounding environment was large. Thus, the plan was changed to connect to the double track section by a spiral adit, which would shorten the process and minimize the impact on the surrounding environment.
By applying the ECI method, a reasonable plan/design have been implemented considering the risk of process. Excavation of the tunnel for this project began in May 2023, and the adit is currently being excavated. During excavation, the impact on the surrounding environment, such as by measuring ground surface subsidence, would be properly assessing.

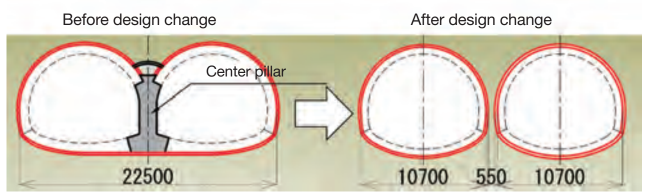
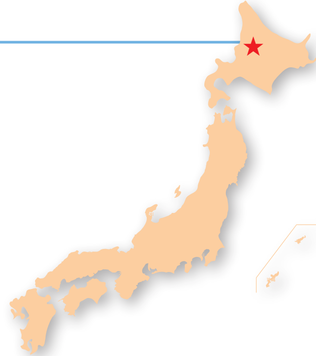


Fig. 3 Parallel Section after Design Change

4. Contact

Official Webpage of YOKOHAMA MINATOMIRAI RAILWAY COMPANY
https://www.mm21railway.co.jp/info/news/2022/05/post-120.html
TEL：045-319-4056
* Currently belongs to Yokohama City Transportation Bureau

Maintenance of the Railway Tunnel Built on Serpentinite



Yusuke NAKANISHI ▸ Deputy section chief, Construction department, Hokkaido Railway Company

The 4,523 m long double-track electrified section railway mountain tunnel, which is currently in service, was put into service on 1 October 1969, one year later than planned, due to numerous deformations such as support works being pushed out toward the inner space due to the squeezing of the ground since the initial excavation.

No significant deformations were observed during the first 18 years of service, but around 1987 the roadbed began to rise and the inner space to shrink in the horizontal direction, similar to that observed when the main tunnel was excavated. In 1996, measures were implemented at night when train operations ceased, since, from the start of measurements, the uplift of the roadbed in some sections was as large as 370 mm, and the inner space was also reduced by 73 mm below the sidewalls which were too large to ignore. Reinforcement work included ground anchors in the sidewalls as a countermeasure against the shrinkage of the inner space, and reconstruction of the joint between the invert and the sidewalls and of rock bolts in the roadbed (Fig. 1) to prevent the uplift of the roadbed, as the joint between the invert and the lower parts of the sidewalls had 'gaps' in its structure and could not transmit axial force.

As a result, the deformation was controlled.

After these measures, the gradual roadbed uplift and inner space reduction continued in other parts of the tunnel, and it was anticipated that if this deformation continued, more maintenance work would be required to keep the trains running safely. It was therefore decided to start countermeasure works again in 2010. The basic policy for the reinforcement work was, as the measures taken in 1996 were sufficiently effective, to use rock bolts to control the deformation in the same way. In addition, as 'gaps' were found at the joint between the invert and the lower parts of the sidewalls, the joint was reconstructed. Specifically, R32 self-drilled rock bolts (n=36) with a length of 9 m were driven in the center of the roadbed section in a downward direction, and R32 self-drilled rock bolts (n=33) with a length of 8 m were driven in the direction horizontal to the inbound line (Photo 1). To reconstruct the joint between the invert and the lower parts of the sidewalls, part of the lower parts of the sidewalls was demolished, reinforcing steel steel bars were jointed to the rebars of the invert and inserted into the sidewalls and fixed using chemical anchors, after which no-shrink mortar was cast (Photo 2).

To check the effectiveness of the countermeasures, the height of the roadbed surface was measured at standard intervals of 5 m in the direction of the railway line. While the maximum uplift rate before the countermeasures (from the start of measurement to the countermeasure implementation) was 13.4 mm/year, after the countermeasure (annual average uplift from the countermeasure implementation to August 2021) the maximum value was -0.1 mm/year, confirming that the situation has been improved (Fig1).

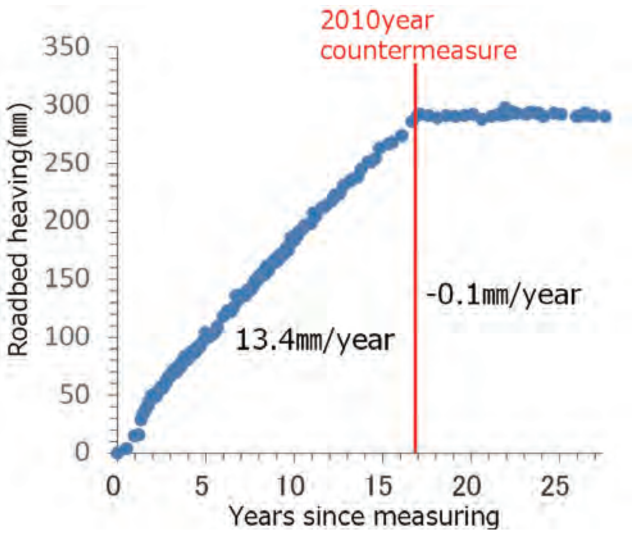


Fig. 1 Roadbed measurement

Photo 1 Self-drilled rock bolt placing

Photo 2 No-shrink mortar placing

6

Diverse Tunnelling in Urban Areas

— Fukuoka City, Nanakuma Subway Line Extension Project (Tenjin Minami to Hakata) —

Toshio HANAMOTO ▸ Engineering Section, Fukuoka City, Transportation Bureau

1. Intro

The length of Fukuoka city Nanakuma Subway line extension project is 1.4km. The civil engineering work began in 2013, and after about nine years of construction including track works, station construction, and utility works, the line was opened on March 27, 2023.
For the extension section, cut-and-cover method was used for the intermediate station, shield method mainly for between the stations, and NATM (New Austrian Tunnelling) method and underpinning method for the section terminus. This paper describes the characteristic construction methods and sections at the end of the section.

2. Mountain Tunneling Method (NATM)

For the 0.2 km section between the stations to Hakata Station, the terminus of the project, an urban NATM was adopted because the required space changes to install a scissors crossing and a base rock layer exists in relatively shallow position.
In determining the cross section, a double-track tunnel was chosen considering the track alignment, construction and economy, and the space for shield to turn. The station junction side was constructed as a triple cross-section that gradually changes. The cross section of the double track is a compound circle.

Fig. 1 NATM Tunneling

3. Underpinning Method

The Hakata Station, the terminus of this extension project, was to be constructed under the existing underground structure to connect with Airport Subway Line. For this reason, the under-pinning method was adopted, in which construction is executed while the existing underground structure is temporarily supported by piles. The structures to be temporarily supported were the underground roadways connected to the JR underground mall parking, the JR underground mall, and the track section of Airport Line. A broad range of structural forms and managers were involved, and the project was extensive as the total supported area was bout 2,700m², with about 290 piles, and the duration was about 5 years.

Fig. 2 Underpinning Method

4. Conclusion

Although the extension length was not very long as a subway construction project, it became a very characteristic subway section in the city as various methods including the shield method, NATM method, underpinning method are used for the underground of the central area of Fukuoka city.

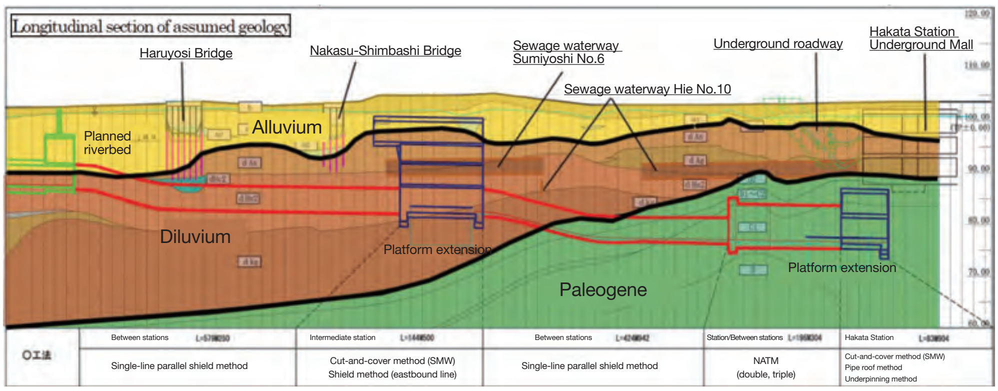


Fig. 3 Longitudinal section of assumed geology

Selection of Displacement Control Measures using Three-dimensional Numerical Analysis in Tunnel Construction Right under the Monorail

Kiyoshi KANEMATSU ► Site Manager, TOBISHIMA CORPORATION, Onakagumi Co., Ltd., Maruo Construction Co., Ltd., Joint Venture

Project outline

The Akamine Tunnel is located in Naha City, Okinawa Prefecture, and consists of two road tunnels, one upper and one lower, with a total length of approximately 1 km. The monorail runs on this route and the minimum separation between the monorail piers and the tunnel is 10 m (Fig. 1). The challenge was therefore to control the displacement of the monorail piers during tunnel excavation so that monorail operations were not severely affected. To meet this challenge, displacement control measures were adopted using three-dimensional numerical analysis, and the displacement was monitored 24 hours a day.

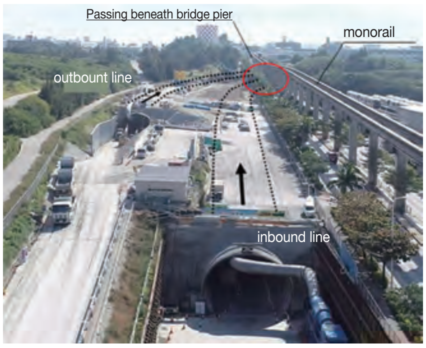


Fig. 1 Site condition

1. Selection of displacement control measures

The displacement control measures for the monorail piers were selected based on simulations of the pier displacement using three-dimensional numerical analysis (FDM analysis: Fig. 2).

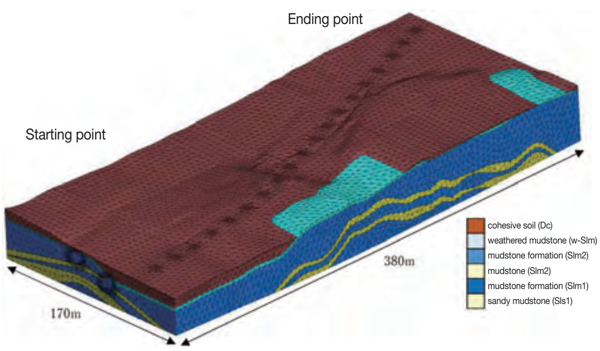


Fig. 2 Three-dimensional model for three-dimensional numerical analysis

Numerical analysis was carried out in two stages: during the design phase and during construction. In the design phase, predictive analysis was carried out to narrow down the countermeasure works. As a result, long steel pipe piling (steel pipe length 9.5 m, one shift length 6 m, circumferential casting interval 450 mm) and early interlocking with primary invert were selected as countermeasure works in the design phase.

Numerical analysis during construction was performed to check the validity of the countermeasure works previously determined. For that purpose, the ground displacements were measured in a test construction to understand the actual ground behavior while the countermeasure works are being implemented. Based on the displacements obtained for each stratum from the test construction, the ground constants were re-established by inverse analysis and predictive analysis was reperformed. The analysis predicted the absolute settlement of the piers to be more than 16 mm (in excess of control level III), so countermeasure candidates A, B and C with upgraded specifications were investigated again. As a result, countermeasure B (with an increased length of the long steel pipe support: 9.5 m → 12.5 m, and an increased angle of hammering: 120° → 160°) was selected capable of reducing the absolute settlement to about control level II (11 mm).

2. Displacement monitoring method

The permissible displacements and control levels of the monorail piers were determined through consultation between the parties concerned. To ensure the safety of monorail operation (trains departed every 10 minutes), the displacement had to be monitored in real time, so automatic measurement of pier settlement and inclination was adopted. The latest measurement results could be viewed on a web page, and an automatic warning e-mail is automatically sent to relevant parties when control levels II and III are exceeded or when displacement increases rapidly. By adopting such a measurement system, the displacement of the monorail piers was monitored 24 hours a day.

3. Construction result

The absolute settlement graph of pier P55, located right above the tunnel, is shown in Fig. 3. All settlements were below control level I. The characteristics of the settlement are as follows:

(i) Although the numerical analysis predicted preceding displacement, no such displacement occurred.

(ii) The maximum settlement per 4 m of tunnel excavation (1.7 mm) was almost the same as the predicted value (1.6 mm).

(iii) The actual settlement turned out to converge when the face had advanced to approximately 25 m forward of the pier.

(iv) The final settlement (7.5 mm) was approximately 60% of the predicted value (12.3 mm).

Compared to the numerical analysis, the actual settlement was smaller, however, the difference was only less than 5 mm. Therefore, it can be concluded that the numerical analysis was able to properly assess the effectiveness of the countermeasure works and substantially predict the actual settlement.

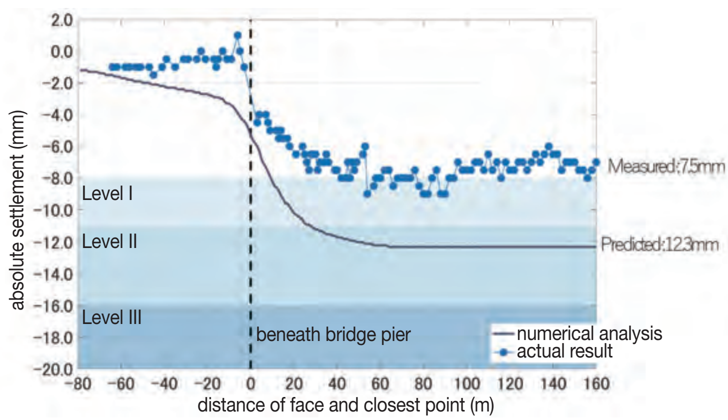


Fig. 3 Settlement graph of P55 (measured and predicted)

Planning a Direct Access Line from Central Tokyo to Haneda Airport

Shinji NAKAMURA ▶ Chief, East Japan Railway Company Structural Engineering Center
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Yasuhiro HIJIKATA ▶ Manager, Tokyo Construction Project Management Office Haneda Access Project Center

Outline

The Haneda Airport Access Line is a construction project to provide direct access to Haneda Airport from various directions. This project will construct three new airport access routes by effectively utilizing ours Tokyo area railroad network and existing stock. The project is expected to "improve access convenience between Haneda Airport and a wide area of the Tokyo metropolitan area," "realize seamless travel by reducing time and eliminating transfers," and "improve transportation substitutability in the event of an emergency. The three routes are the East Yamanote route (for Tokyo), the West Yamanote route (for Shinjuku), and the Coastal Area route (for Shin-Kiba). The three routes merge at Tokyo Freight Terminal and connect to Haneda Airport via a new access line (Figure 1). The following is an overview of the East Yamanote route project and construction details.

1. Overview of the East Yamanote route project

This project is divided into three major sections. From the starting point (Tokyo direction), there are (1) a 1.5-km section connecting to the existing line, (2) a 3.4-km section to renovate the existing line, which is currently in disuse, and (3) a 2.5-km section that was improved heading towards the Tokyo Freight Terminal. After that, the line connects to the new access line section (Figure 2). In section (1), shield tunnels and approach section will be constructed to branch off from the existing line and cross under the existing line. (2) is to renovate the existing line, which is currently in disuse for more than 20 years. (3) is to construct lines for the detention of vehicles and maintenance vehicles necessary for operation. Of these, the particulars of the construction of (1) are described below.

2. Construction Features

In section (1), it is necessary to create space for a new line while operating the existing line. Specifically, the existing draw-out track is to be removed, and space for the new line is to be created by switching tracks three times (Figure 3). Since this section is excavated directly under an important line section with so many trains in the Tokyo metropolitan area, it is particularly important to consider train operations. Since most of the work is performed inside the railway tracks, it is necessary to take measures to keep trains out of the work area. Therefore, work hours are generally limited to 1:00 to 4:00 a.m., and the construction work is also subject to time constraints. Despite these restrictions, we are working to ensure the safety of trains and to implement the project as soon as possible.

Fig. 1 Haneda Airport Access Line Concept

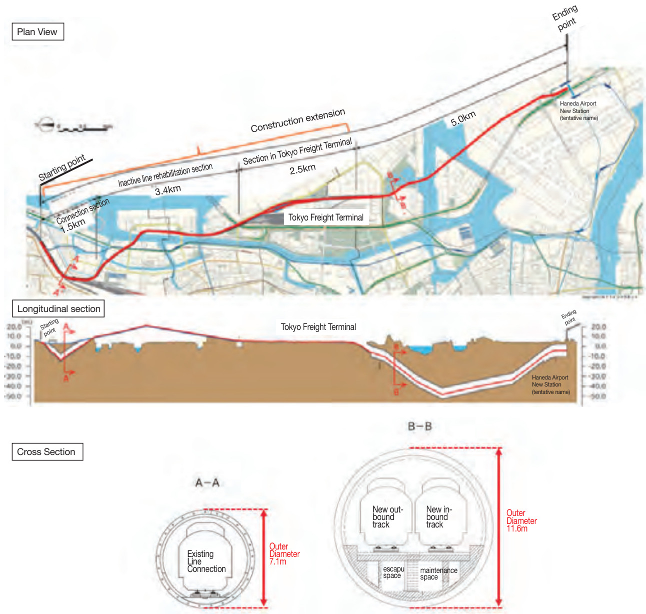

Fig. 2 Overview of the construction work of the East Yamanote Route

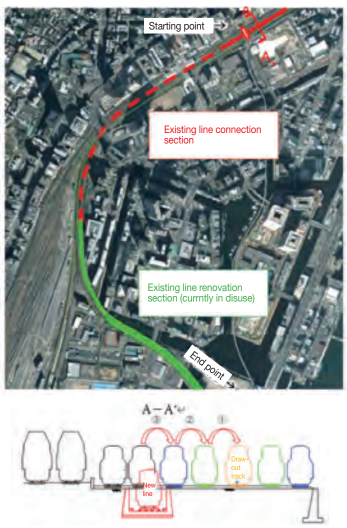

Fig. 3 Outline of existing line connection section

Tokaido Shinkansen with over 50 Years of Operation — Major Renovation of the Tunnels —

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Nobuhito INOUE ▶ Senior Staff, Structures Section, Tracks and Structures Department, Shinkansen Operations Division, Central Japan Railway Company

Introduction

The Tokaido Shinkansen, which began its commercial operation in 1964 as the world's first high-speed rail line, has supported Japan's economy as a major artery between three metropolitan areas of Tokyo, Nagoya, and Osaka. Maintaining the soundness of its civil structures for the future is achieved through daily inspections, repairs and reinforcements. However, the aging of the structures remains an issue, and eventual replacement or equivalent-level renovation of the facilities is necessary. Therefore, preventive renovation of civil engineering structures is being carried out. This paper focuses on the overview of the tunnel renovation.

1. Current state of the tunnels and outline of the renovation

The Tokaido Shinkansen Line has 66 tunnels, with the total length being 68.6 km. Most of them were constructed by timbering support method, the mainstream at the time of construction. With this method, voids tend to occur on the outer surface of the lining, causing a loss of integrity with the ground and lowering the bearing capacity of the tunnel lining. Thus, for all tunnels, preventative measures against deformations started as a major renovation project. To increase the bearing capacity of the lining by integrating the lining and the ground, we perform "Injection behind lining," filling the voids with grout agents, "crack grouting," injecting resin material into existing cracks, as well as "rock bolting" (Figure-1).

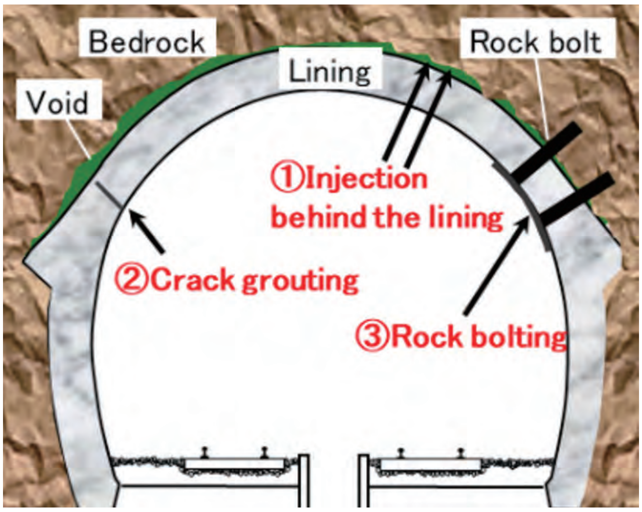

Fig. 1 Outline of the major renovation

2. Details of the renovation

2-1 Injection behind the lining

Injection behind the lining has conventionally been used as a basic countermeasure to improve the load-bearing capacity of the lining when a void exists between the lining and the ground. However, voids have been confirmed even where injection behind the lining has been performed in the past, meaning that it may not been sufficiently effective. Therefore, we studied the required performance of grout and methods to improve filling performance. Cementitious solidifiers with plasticizers added are used for better fluidity and repletion. Two types of construction methods are adapted, depending on the conditions of the sites; One in which the grout is pumped to the injection point from the plant outside the tunnel, and the other in which the grout is mixed and injected at the injection point with the plant mounted on a maintenance vehicle inside the tunnel. (Photo-1)

Photo 1 Injection behind the lining

2-2 Crack grouting

Injection behind the lining improves the load-bearing capacity of tunnels, but the air pressure fluctuations and train vibrations caused by train running may create cracks of the lining, leading to flaking of concrete masses during earthquakes. To control such damage, resin material is injected into the cracks.

2-3 Rock bolting

Although Injection behind the lining and crack grouting improve load-bearing capacity of the tunnels, the lining may have obvious weak points, such as cracks forming large concrete masses or concrete of extremely poor quality. Therefore, rock bolting is also conducted to ensure long-term safety. (Photo-2)

Photo 2 Rock bolt installation

Conclusion

This is an overview of the major renovation of the Tokaido Shinkansen tunnels. We will strive to complete the project to extend the service life of civil engineering structures.

Results and Evaluation of Measurements at the Seikan Tunnel after 35 Years of Operation

Yuichi KOBARA ▸ Chief, Maintenance Division, Construction Coordination Department, Hokkaido Shinkansen Construction Bureau, Japan Railway Construction, Transport and Technology Agency (JRTT)

1. Introduction

The Seikan Tunnel is a railroad tunnel connecting Aomori Prefecture and Hokkaido, Japan (Figure-1), and is the world's longest railroad tunnel with an undersea section. The tunnel was put into service in March 1988 as the Tsugaru Kaikyo Line (conventional line), followed by the Hokkaido Shinkansen Line in March 2016. Using a dual gauge that is rarely seen in the world, it has been in service as an important main artery for passenger and cargo logistics between Honshu and Hokkaido. The Seikan Tunnel consists of a main tunnel where trains run, a working tunnel for maintenance, drainage, and ventilation, and a pilot tunnel. The main tunnel is 53.85 km long, of which 23.30 km is below the seafloor, reaching 240 m below sea level at its deepest point (Figure 2). The Seikan Tunnel is in a special environment where high water pressure and an inexhaustible seawater must be taken into account. Therefore, ever since the opening of Tsugaru Kaikyo Line, surveys and measurements have been conducted continually for the section under the seafloor through "Seikan Tunnel Disaster Prevention System" and "regular measurements." The following is an overview of the application of obtained data.

2. Utilization of Monitoring Data in the Seikan Tunnel Disaster Prevention System

The Seikan Tunnel Disaster Prevention System is in place to ensure the safe operation of trains in the Seikan Tunnel (Photo-1). The system displays real-time data from seismographs, strain meter, and water inflow meter, and those data are used to support train operations and to evaluate tunnel health.

2-1 Seismographs and Strain meters

Seismographs and lining strain gauges are installed in the Seikan Tunnel at the following four locations which were associated with difficulties in tunnel construction: the Izumi Fault (16K), the volcaniclastic dike (21K), section with unconformity in strata (30K), and the F10 fault (33K). The dynamic behavior of the tunnel lining at the time of earthquakes is monitored to determine if there is any damage to the tunnel, and at the same time, the longitudinal and transverse displacement of the tunnel is monitored during normal conditions.

2-2 Water Inflow Meter

The amount of water inflow is the most important item to be monitored in order to maintain the function of the Seikan Tunnel, which is under the seafloor. The water inflow meters are installed at 27 locations along the drainage channels of the main, working, and pilot tunnels, and are used not only to determine the effects of earthquakes, but also to analyze the variation of water inflow amount under normal conditions to verify the sealing performance of the grouting in the tunnel area. The water inflow has been slightly decreasing since the start of the measurement, but the trend is similar to that of other undersea tunnels in Japan, such as the Kanmon Tunnel.

3. Utilization of Periodic Measurement Data of Maintenance Management Items

In the Seikan Tunnel, various measurements are periodically taken to evaluate the structural integrity and to obtain maintenance management indicators such as the need for countermeasures. The following sections introduce the inflow water pressure meter and inner space displacement meter.

3-1 Inflow Water Pressure Meter

Water inflow pressure meters are installed at five locations in the working shafts which are associated with difficulties in construction and areas with geological difficulties. They are used for seepage flow analysis (Figure 3) together with water inflow data to verify the effectiveness of water sealing around the tunnel.

3-2 Measurement of Inner Space Displacement

The internal displacement of tunnel cross-sections is measured using a 3D light wave measuring device, and measuring points are at 77 cross-sections of the main tunnel and a total of 202 cross-sections of the working and pilot tunnel. The displacement data was analyzed using the finite difference method (Figure 4) and a ground degradation model to determine/implement necessary countermeasures for the structural stability. Note that the accumulated displacement of the main tunnel is 6mm at the maximum, which is lower than the level of taking countermeasures, but the frequency of measurements is being reviewed based on the displacement estimations and the damage status.

Fig. 1 Seikan Tunnel Location Map

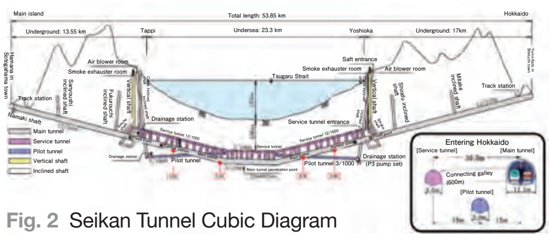

Fig. 2 Seikan Tunnel Cubic Diagram

Photo 1 Seikan Tunnel Disaster Prevention System

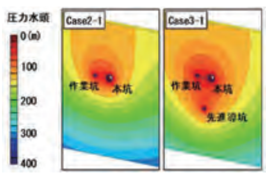

Fig. 3 Seepage Flow Analysis Diagram

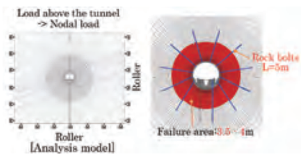

Fig. 4 Finite Difference Method Analysis Diagram

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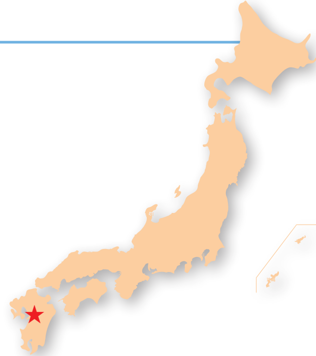


Restoration after the Kumamoto Earthquake

— Tateno Tunnel of JR Hohi Main Line —

Takahiro KAMIKAWA ▸ KYUSHU RAILWAY COMPANY, Hakata Maintenance Line Area

Daisuke MATSUMOTO ▸ Kumagai Gumi Co.,Ltd, Kyushu Branch, Civil Engineering Department

1. Introduction

The Kumamoto Earthquake in April 2016 caused severe damage to the Tateno Tunnel of Hohi Main Line of Kyushu Railway Company, including cracks and spalling of the lining concrete inside the tunnel and rupture of the portal. The repair work for the large-scale slope failure caused by the earthquake affected the tunnel, and its full-scale restoration began in 2019, with the entire Hohi Main Line resuming operation in August 2020.

This paper reports the damage to the tunnel by the earthquake, presumed cause of the damage and the restoration method adopted.

2. Outline of the Tateno Tunnel

The Tateno Tunnel is a 218m-long, single-track, non-electrified tunnel completed in 1918. Its lining was constructed with cast-in-place concrete for the side walls and a mixture of brick and cast-in-place concrete for the arch and crown, a structure often seen in tunnels of the time.

3. Damage to the Tateno Tunnel

The foreshock of the Kumamoto Earthquake occurred at 9:26 p.m. on April 14, 2016, with the magnitude of 6.5 at the epicenter in Kumamoto region, and the main shock at 1:26 a.m. two days later, with the magnitude 7.3 at the epicenter. Significant deformation was observed in the following sections of the tunnel.

(1) Damage near the center of the tunnel

Cracks and spalling of the tunnel lining occurred due to seismic shaking. In particular, the lining was squeezed by approximately 70 mm to the inner side near the center of the tunnel (Photo-1).

Photo 1 Portal deformed conditions

(2) Portal rupture

The crown of the portal was ruptured by a vertical crack with an opening width of a few dozen millimeters, and bricks fell from the crown of the lining at the boundary. In addition, the sidewall of the lining, about 5 m from the portal, was squeezed 35 mm to the inner side of the tunnel (Photo-2).

Photo 2 Lining deformed conditions

4. Presumed cause of the damage and restoration method

Based on the survey boring and on-site inspection of the deformed section, the cause of the damage was presumed and operation was resumed in August 2020 after the following restoration work.

(1) The cause of the damage and restoration method near the center of the tunnel

Based on the results of boring survey, it was presumed that the damage was locally increased due to the different responses to seismic motion. This happened because the stratum boundary between andesite and tuff breccia, which have different relative strengths, were located in the damaged section. Restoration was performed with internal reinforcement but since the margin of the building limit was small, T3 panel method, in which steel supports and high-strength thin panels cover the inner lining, was adopted. (Photo-3). The thin panels, made of high-toughness cement board with aramid fibers structured in two directions attached, have a load capacity of 8 kN/ m^2 and the minimum construction thickness can be reduced to about 3 cm.

(2) The cause of the damage and restoration method at the portal

It was presumed that the ground displacement due to seismic motion was particularly large because the portal was located at the tip of a narrow ridge-like topography and the ground was relatively soft with a small overburden. The broken sections of the portal were repaired with reinforcing plates and rock bolts. The tunnel was integrated with the ground using grouting type forepiling (AGF method) and a 50-cm-thick face wall was constructed in front of the portal (Photo-4).

Photo 3 Inner reinforcing by T3 panel method

Photo 4 Portal restoration conditions

Construction of Single-line Parallel Slurry Shield Tunnel Passing Directly under Private Constructions

— Kita Osaka Kyuko Line Extension Project —

Kentaro HATA ▶ Section Manager, Construction Department KITA-OSAKA KYUKO RAILWAY CO.,LTD.
Keiji TANAKA ▶ Associate General Manager, Civil Engineering Department, Kansai Branch Kumagaigumi Co.,Ltd.

Outline

To construct a single-line parallel railway tunnel directly under private building with small clearance (minimum clearance of 1.46m (about 0.2D)), shield tunneling has been done while strictly managing the face stability and back-fill grouting in order to prevent impacting on buildings (Figure 1).

1. Impact Analysis and Shield Tunneling Management

The behaviors of existing buildings to which the shield gets closer have been understood by 2D FEM analysis, and based on the results, managers had discussed and set the measurement control values. The standard values provided by "Recommendations for Design of Building Foundations" (Architectural Institute of Japan) were applied to the limit values for buildings other than high-rise condominiums.
For the high-rise condominiums, a 3D FEM analysis was performed, and structural calculations were performed using the ground displacements obtained from the analysis as input values.
The structural details were entrusted to a high-rise condominiums design firm, and it was confirmed that the design criteria were satisfied. The ground displacement at that time was managed as the limits of the control values.
During the implementation of the shield tunneling, face pressure and back-fill grouting pressure were changed in a planned way just before reaching the intermediate shaft and just after re-launching to monitor ground surface and ground displacement in the soil, and optimal control values for tunneling were set for each aboveground structure.
In addition, in order to promptly feedback the measurement values to tunnelling management, automatic measurements were mainly taken in buildings above the shield passage area, while level surveys and 3D measurements were used where the passage crosses a road. Further, by injecting intermediate filling and using back-fill material that develops strength fast, ground settlement upon shield passage including the period of pausing tunneling and tail void settlement were controlled. When excavating near low-rise commercial buildings and high-rise condominiums in the vicinity of the arrival area, even small changes in face soil pressure or back-fill grouting pressure could affect the buildings due to the small soil cover. Therefore, the target grouting pressure was changed according to the earth cover, and grouting limits and upper and lower limits were set for strict construction management.

2. Result

Through those efforts described above, the shield tunneling was completed (Photo-1) without exceeding the displacement or control values predicted based on preliminary analyses (Table-1).

Table 1 Table of Measured Foundation Displacement for High-rise Condominium

10 Types of Low-rise Block					
Measurement Point	Max. Value	Min. Value	Primary Control Value	Secondary Control Value	Analysis Value
10-I	0.14mm	-1.78mm	+0.6mm -2.4mm	+0.8mm -3.4mm	+1.02mm -4.79mm
10-H	0.24mm	-0.47mm	+1.7mm -2.8mm	+2.4mm -3.9mm	+3.39mm -5.47mm
10-G	0.36mm	-0.42mm	+2.8mm -2.8mm	+3.9mm -3.9mm	+5.57mm -5.57mm
10-F	-0.07mm	-0.71mm	+0.6mm -1.2mm	+0.8mm -1.7mm	+1.06mm -2.32mm

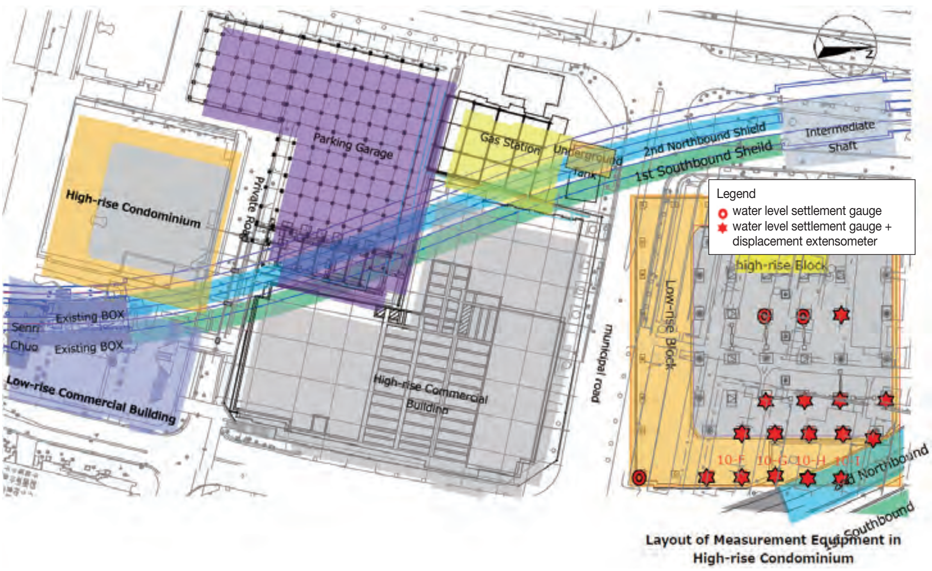


Fig. 1 Northern Part of Senri Chuo after Completion of Construction (new tunnel in the foreground, existing tunnel in the background)

Double Support Structure Overcomes Load of 610m Earth Pressure

Aokuzure Pass Tunnel - Nagano Construction Site

Yoshihiro KOIKE ▸ Iida Office of National Highway, Chubu Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism

1. Project Overview

Construction of the San-en Nanshin Expressway, a high-standard road approximately 100km long is underway from Iida City, Nagano Prefecture to Hamamatsu City, Shizuoka Prefecture. Once opened, it will become an important route that will connect the Chuo Expressway and the Shin-Tomei Expressway and contribute to strengthening regional cooperation and the development of the Mikawa, Enshu, and Minami-Shinshu regions.
This tunnel is located approximately in the middle of the San-en Nanshin Expressway, approximately 500m west of the Median Tectonic Line. It is located in a mountainous area with steep terrain formed by fault activity and river erosion, and the maximum earth cover was 610 m. The main geology was porphyry mylonite, a fault rock that underwent plastic flow due to thermal degeneration and dynamic metamorphism caused by high temperatures and pressures.

2. The Biggest Challenge in Tunnel Construction

Empirically, it is assumed that a large load from the ground acts on the tunnel when the earth cover exceeds 500m.
In the Nagano section of this tunnel (L = 2,854m), the tunnel was constructed with a standard support structure from the beginning of excavation to around 2,730m. However, although the compressive strength of the bedrock is relatively high at 1,000 to 3,500 MPa, buckling of the steel arch supports, cracks in the sprayed concrete, and fractures of rock bolts were confirmed, forcing the support structure to be modified (Photo 1).

3. Countermeasures to Solve the Problem

When constructing a tunnel with a large cover, it is recommended to increase the rigidity of the support such as using double supports to resist the load from the ground, or to release stress from the ground by using compressible support members.
For this tunnel, a double support structure using high-strength sprayed concrete with a design standard strength of 36N/mm^2 was applied, based on the experience in the Shizuoka construction area, where the support structure had to be changed due to the load from the large overburden.
In addition, for sections where the earth cover exceeds approximately 600m, it was decided to apply ultra-high strength sprayed concrete with a design standard strength of 54N/mm^2 (Fig.1 and Photo 2). By applying a double support structure using high-strength sprayed concrete and ultra-high-strength sprayed concrete, it was possible to continue the tunnel excavation without causing damage to the tunnel support members.
The amount of displacement and deformation of the tunnel after excavation was approximately 100 mm for the crown settlement and 25 mm for the convergence at the stage of the single support construction, but by constructing the double support, subsequent displacement and deformation were reduced. It was confirmed that crown settlement and convergence after the construction of the secondary support structure were reduced to 10mm for each.
The breakthrough of this tunnel was achieved in May 2023. Construction of the concrete lining is currently underway, with the goal of completion by Fall of 2024.

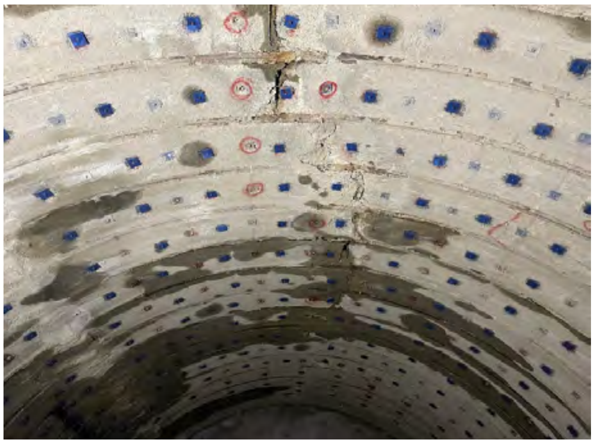


Photo 1 Damage of support members at large earth pressure area

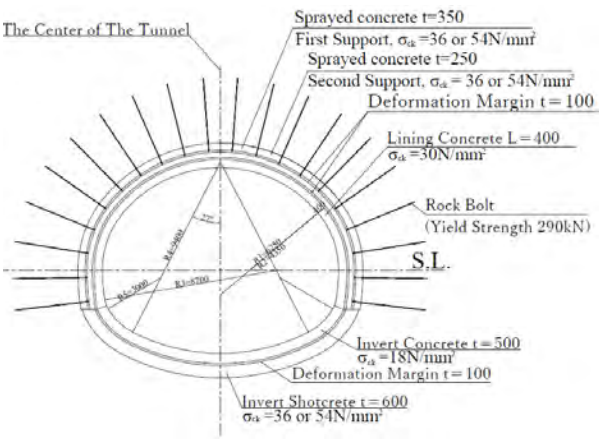


Fig. 1 Construction support pattern of Countermeasure work

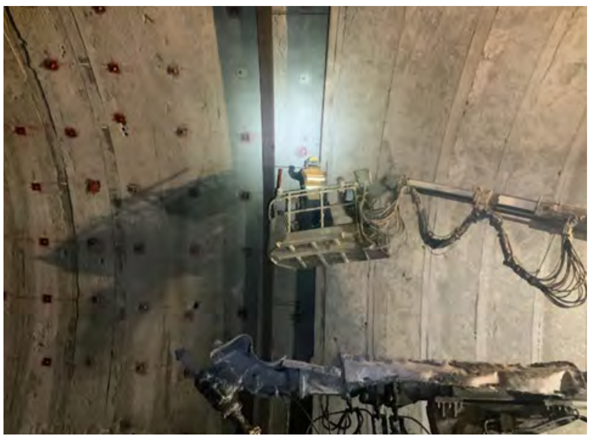


Photo 2 Construction status of the double support structure

Excavation of World's Largest Urban Mountain Tunnel

Takeshi KAWASAKI ▶ General Manager, Yokohama Construction Office, Kanto Regional Head Office, East Nippon Expressway Company Limited

Daisuke MATSUMOTO ▶ Manager, Shodo Construction Section, Yokohama Construction Office, Kanto Regional Head Office, East Nippon Expressway Company Limited

Introduction

Shodo Tunnel is a 0.5 km long tunnel located where the Yokohama South Ring Expressway (3 lanes on each side, total length 8.9 km), which is a part of the Metropolitan Inter-City Expressway, connects with the Kamariya Junction of the Yokohama-Yokosuka Road.
There is a junction in the Shodo tunnel where 4 main line tunnels and a ramp tunnel branch and join, and an extra-large tunnel with a width of 29.5m and a cross-sectional area of 485 m2, encompassing a maximum of five lanes, is excavated using the mountain tunneling method. As a highway tunnel by the mountain tunneling method, it has one of the world' s largest excavated cross-sections. In this paper, the characteristics and implementation status of the construction of the junction.

1. Outline of Junction Section

As the junction where the main lines and a ramp tunnel branch/join, the cross-sections of two large-section outbound/inbound tunnels are widened approximately every 20m to 30m to form an extra-large cross-section with the maximum width of 29.5 m for inbound line and 25 m for the outbound line. The construction can also be characterized by the fact that the two large-section tunnels are constructed extremely closely with the separation of about 1m (Fig. 1). The earth covering is less than 1D (D: tunnel diameter) with 7m to 14m, and the minimum separation from the residence on the ground is 6m (horizontal distance to the ground).

The geology is dominated by tuff sandstone (Nts layer) of the Neogene Pliocene ~ Quaternary Pleistocene, and the sandstone-mudstone alternating zone intervening with the pumice mudstone layer is distributed on the lens.
The Nts layer is massive homogeneous soft rock formation with few fractures, but the uniaxial compressive strength varies largely between 1.4 to 5.9MN/m2, and with thin layers of pumice and mudstone interbedded, there was concern that these may affect tunnel deformation and face stability.

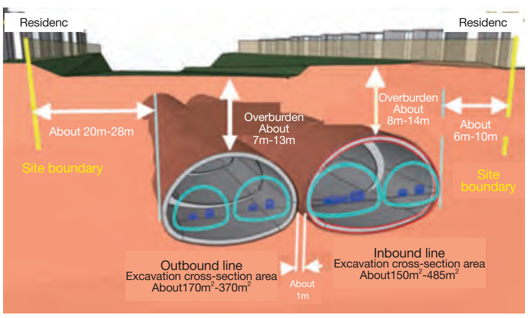


Fig. 1 Schematic Diagram of Junction Section

2. Construction Status

The excavation of the confluence section was a procedure for widening the large cross-section after excavating the advanced conduit shaft.
The division of heading in the original plan was 3 sections (upper, lower, and invert section) assuming a general machine configuration, but it was anticipated that the deformation of the tunnel would be relatively large due to the rather flat cross-sectional shape of the temporary closure of upper half section. Therefore, a large excavation machine was used to lower the formation level of the upper half section down to the S.L. (spring line) to give the temporary closure cross-section more stability (Fig. 2).
In addition, in order to shorten the time until excavation and temporary closing, all construction machines such as excavation, shoring, erection, and spraying were organized into two units.

Besides, the lower section and invert were excavated and supported by 1 meter together to shorten the time that the natural ground is exposed and improve the closure effect through prompt installation of supporting.

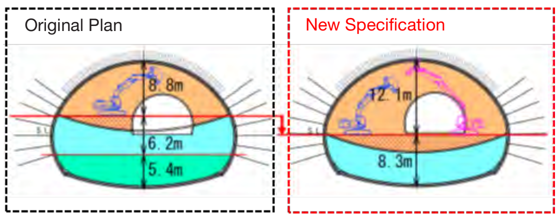


Fig. 2 Change in Division of Heading

During excavation, various measurements and monitoring such as surface settlement and underground displacement were conducted. The standard control values are set for each construction phase in anticipation of future increases in measured values. The measurement results at the completion of inbound line excavation were generally within 50% of the standard control values. The excavation behavior was confirmed to be within the range of predicted analytical values.

Fig. 3 Maximum Cross-section Excavation Completed

- Excavation for widening of the inbound line began in January 2022, and excavation of the largest cross-section was successfully completed in March 2023 (Fig. 3, 44 order-takers lined up).

In the future, we are going to excavate its twin tunnel, an unprecedented large-scale tunnel with a minimum separation of 1m from the other, as the outbound line tunnel, which has about the same cross-section as the inbound tunnel. We will pursue safe and secure completion of the construction through construction innovations and monitoring of measurement data.

Mountain Tunnel Construction in Fragile Ground in Volcanic Regions

— National Highway 57th Takimurozaka Road, East Takimurozaka Tunnel Construction (Phase I) —

Hirohito TABATA ▸ TAISEI CORPORATION

1. Introduction

The Kumamoto 57th Takimurozaka Tunnel is a 4.8 km long road tunnel located on the east side of the Aso Caldera in Kyushu which located at the south-western end of Japan's four main islands. It was successfully penetrated in June 2023, but significant deformations occurred in the fragile geological sections unique to volcanic regions. Measures were taken against the deformations that occurred in the fragile geological section, which is composed of unconsolidated volcanic ash from Quaternary pyroclastic flow deposits, including those to prevent leg settlement, those to reduce water pressure using drainage boreholes and lining reinforcement in anticipation of future loading on the lining. This report specifically describes the measures to prevent leg settlement.

2. Status of the deformation

This tunnel is a large-section tunnel with a flat shape and an excavated cross-sectional area of more than 100 m2, as shown in Fig. 1. In the fragile geological section, cracks appeared in the shotcrete, the main support member, and a crown settlement, which exceeded the control value of 45 mm, was measured inside the tunnel. In this section, a sand and gravel layer were distributed in the lower half of the section, as shown in Fig. 2. The uniaxial compressive strength of this layer was less than 0.2 MPa, and softening due to ground water was also evident.

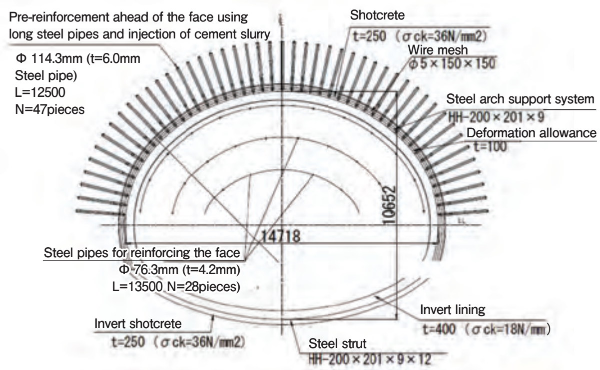


Fig. 1 Support structure in fragile geological section

Fig. 2 Geological conditions of the face in the section where the deformation occurred

Fig. 3 shows the settlement displacement measured at a cross section located in the section where the deformation occurred and 459 m away from the portal. A significant settlement due to excavation was observed in the 12 m to 23 m section away from the face after the primary invert completion and before the leg piles described below were installed, especially in the crown, left shoulder and left leg areas.

3. Countermeasure works and effects

Even after primary invert completion as a countermeasure againt settlement, displacement continued to increase with the progress of excavation. Based on geological investigations, geological observations and displacement trends, it was concluded that the ground bearing capacity was insufficient, particularly on the left side. To prevent settlement, leg reinforcing piles shown in Fig. 4 were constructed on the left side leg areas with an extension of 86 m.

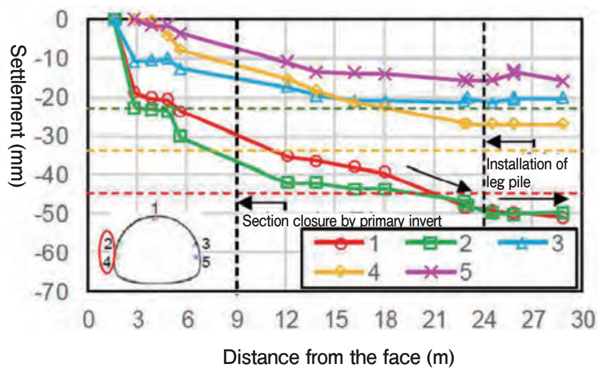


Fig. 3 Settlement measured in fragile section

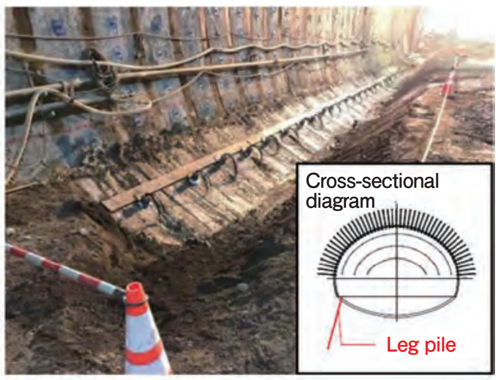


Fig. 4 Construction of leg piles

The need for leg piles was judged based on the displacement speed trend after the primary invert completion and whether the amount of settlement exceeded the control value of 34 mm before displacement converges. As can be seen from Fig. 3, after the leg pile installation, the displacement generally showed a trend of convergence, especially at the points 24 m or farther away from the face, confirming the effectiveness of this countermeasure work.

Tunnel Widening Construction Considering the Safety of Users and the Living Environment of Nearby Residents

Atsuo NOJI ▶ Joint Venture of TOBISHIMA CORPORATION and Ito Doken Co., Ltd.

Outline of Construction

Kuradama Tunnel, located in Kimitsu City, Chiba Prefecture, is a road tunnel with a length of 145 m constructed in 1953 using the sheet pile method. Due to the narrow width of the tunnel, it did not allow normal vehicles to pass each other, so it was necessary to widen the existing tunnel without traffic control. In addition, this project required the selection of construction equipment in consideraction of construction restrictions because two protectors were to be installed sequentially, the movement of the protectors with traffic control only at night to minimize the Impact on general traffic, and the selection of construction methods and safe construction in consideration of the living environment of residents in the vicinity of the tunnel portal on the termical side.

1. Outline of the Road Widening and Tunnel Excavation

The geology around the tunnel consists of alternate layers of mudstone and sandstone, with mudstone-dominated and sandstone-dominated sections appearing repeatedly. The sedimentation environment is estimated to be in the middle to upper part of the continental slope.
Figure 1 shows a summary of the construction procedure.
As an excavator, an erector-equipped shotcrete machine was employed, which can perform the entire process from the first spraying to the construction of tunnel supports and the second spraying without a time lag, even in a section with poor ground conditions. In addition, considering small overburden (maximum overburden: 24 m) along the entire line, the upper bench length was shortened to a minimum of 5 m to minimize tunnel loose areas and stabilize the cutting face (Photos 1 and 2).

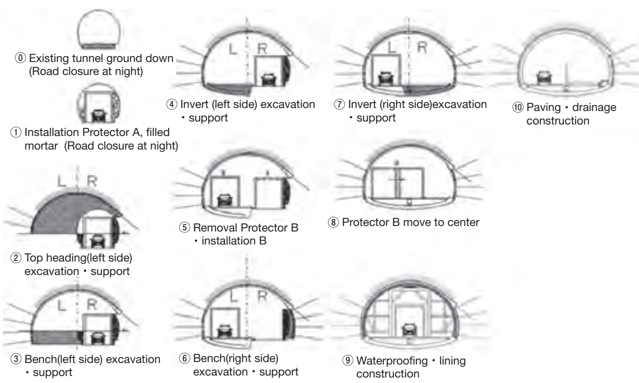


Fig. 1 Construction procedure of the road widening without traffic control

Photo 1 Installation of the tunnel support

Photo 2 Concrete spraying (under tunnel ventilation)

2. Movement of the Protector to the Center and Environmental Measures

Movement of Protector B to the center of the tunnel required extremely strict conditions: the 158-m-long protector had to be moved 3 m in the transverse direction, and the work had to be performed during the nighttime closure period from 9:00 p.m. to 5:00 a.m.
To address these construction conditions, the following measures were taken: (1) the protector was separated into blocks of 10 m each, (2) special rollers were installed at the lower ends of the four corners of each block, and (3) two sets of motorized chain hoists were installed for each block on the day of the movement, and the blocks were towed from one side. As a result, the movement of all the blocks was successfully completed in one night (Photo 3).
As for measures to protect the living environment of the nearby residents, there were concerns about the impact of noise generated during the tunnel construction on two private houses located near the tunnel portal on the terminal side. As a measure against this issue, a sound insulation wall (H = 12 m) was installed at the tunnel portal. In addition, before tunnel penetration, ground (2 m in height) was left at the upper half of the tunnel portal as a bulkhead to provide sound insulation. By implementing the above measures, the lower half excavation of the L side of the tunnel and invert excavation was successfully carried out day and night using a hydraulic tunnel excavator instead of a large breaker, despite the proximity of private houses to the tunnel portal on the terminal side. During the construction period, there were no complaints from residents in the vicinity, and the construction noise and vibration levels met environmental regulations (Photo 4).

Photo 3 The movement of Protector B to the center

Photo 4 Installation of an electrostatic precipitator and a sound insulation wall (H = 12 m)

3. Conclusion

In this project, the two protectors used for protecting normal vehicles until the completion of the lining placement were successfully installed, moved, and removed within the limited time period. Furthermore, the selection of the construction equipment was made in consideration of the safety of third parties and the conditions of construction in the narrow space where the protectors were located. In addition, the road widening work was successfully completed without any complaints or troubles from the surrounding residents as a result of the preliminary construction and measures taken after repeated studies on various issues, such as the change to a tunnel ventilation system using the existing tunnel and noise reduction measures at both tunnel portals.

First Ever Tunnel Invert Reinforcement on a Highway Using Timbering Support Method

Masayuki SHIMIZU ▶ Section Manager, Nagaoka Management Office,
East Nippon Expressway Company Limited

Outline

The outbound line of the Yoneyama Tunnel of the Hokuriku Expressway is a 1,616m long tunnel constructed using the timbering support method, and has been in service for about 40 years since 1983. It is mainly composed of Neogene mudstone and sandstone-mudstone alternation layers, and according to the results of X-ray diffraction analysis, it contains trace to small amounts of smectite, a swelling clay mineral. The pavement surface rose by a maximum of 108 mm in 1996, and the Chuetsu-oki Earthquake in 2007 caused damage such as partial peeling off of the lining surface. Since the road surface is still rising, renewal work was conducted to install new inverts in 2022. This work lasted for a total length of L=450m at locations where: seismic effects by the Chuetsu-oki Earthquake and other reasons existed, and where road surface displacement was 20 mm or more and displacement speed was generally 0.5 (mm/year) or more. Since the inverts were to be constructed on an expressway that was still in service, the plan was to construct the entire width of the invert in one piece, while closing off the outbound line and switching the outbound traffic to the inbound line for two-way traffic.

1. Planning the Reinforcement of Inverts

Tunnels constructed using the timbering support method are reverse-wound, with the upper half concrete of one 12-meter span of lining constructed first, and then the sidewall concrete is placed. This results in having joints on the upper half and sidewalls, and if the lining footings were excavated at one time, there is a possibility of having deformities such as lining settlement and cracks in the joints. The length of the invert excavation was compared using numerical analysis, and was decided at the half of the 12 m span of the lining, L=6 m.
As a preliminary work for the invert installation, reinforcing bolts were cast prior to the countermeasures. The purpose of the sidewall reinforcement bolts was to suppress the settlement of the lining and deformation of the sidewalls during the invert excavation. A total of 1,812 bolts were cast in the L=450 m length of the invert countermeasure, three on each side of each section, L=4 m, with a casting interval of 0.9 m pitch in the vertical direction and 1.5 m pitch in the tunnel axis direction (Figure-1).

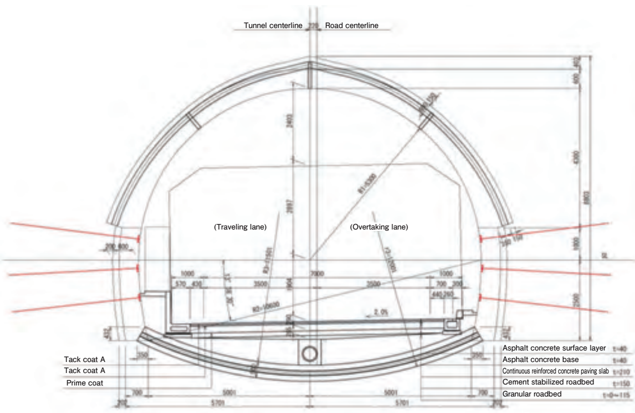


Fig. 1 Cross-section of reinforcement bolt

2. Steps in Invert Excavation

For the invert excavation, the L=6m block was constructed in advance of all odd-numbered spans, as shown in Figure-2, and all even-numbered spans were constructed in the back row. The construction of the initial excavation of the first excavation span was carried out with enhanced monitoring and meticulous care. The sequence of each construction was as follows: (1) excavation of the center, (2) excavation of the overtaking side earth level, (3) excavation of the traveling side earth level, support installation, formwork installation, and pouring of invert concrete, while confirming validity based on the measurement results together with the construction status (Photo-1).

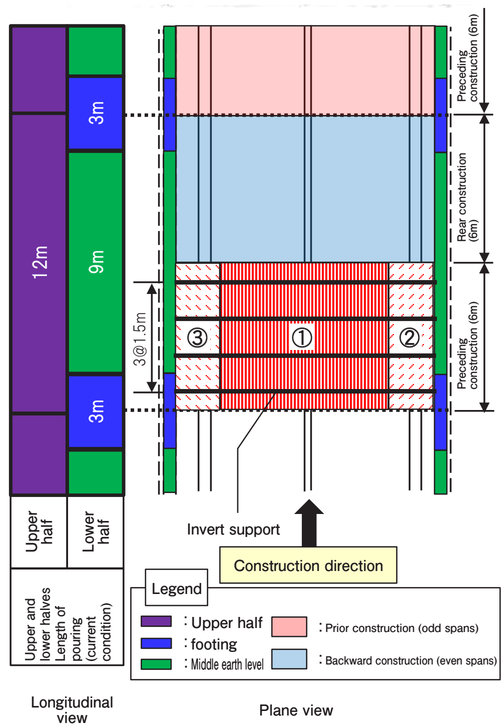


Fig. 2 Excavation layout

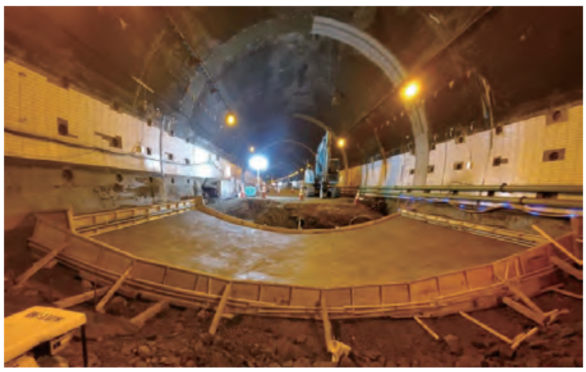


Photo 1 After placing invert concrete

Breakthrough with Using of Various Countermeasure Works in Landslide Topography and Cliff Cone Deposit Sections

Shunsuke MIYAGAWA ▶ Head of Construction Site, OBAYASHI CORPORATION
Hiroto YAMANAKA ▶ Construction Supervisor, OBAYASHI CORPORATION

The Kuji Osanai Tunnel Project, in Kuji City on the northern coast of Iwate Prefecture, is the construction of a 1445.3 meter-long road tunnel with the cross-sectional area of 109 to 128 ㎡. This paper describes the countermeasures for the tunnel's small overburden section with landslide topography, the boundary fault section in fracture zone, and the talus cone sediment at the tunnel portal.

1. Small overburden with landslide topography

The section with a minimum of 6 m overburden consisted mainly of conglomerate, with unconsolidated talus cone sediment and soil in the upper part. Landslide topography was also observed.

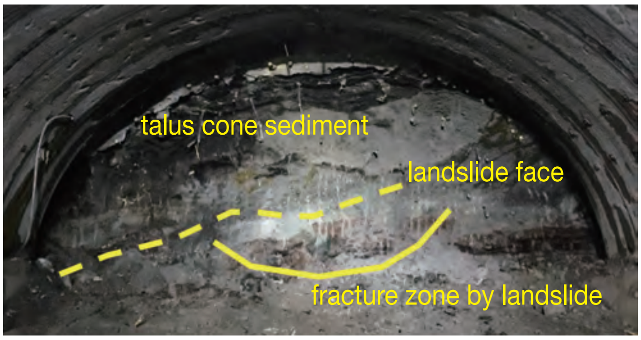


Photo 1 Landslide face

To prevent ground loosening by excavation, following measures were taken while monitoring the behavior of the landslide soil mass:
-early closure by primary invert
-dewater boring
-long steel pipe forepiling and long facebolt
-flash setting shotcrete

2. Boundary fault area with fracture zone

The boundary fault was located near the center of the tunnel length. A localized collapse occurred in front of the assumed point. Excavation was continued on the assumption that it was a branch fault rather than the main fault, but a large-scale collapse occurred at a point 2 meters further down the tunnel.
Based on the scale of the collapse, a boundary fault was assumed, and a borehole camera was used above and in front for void investigation to confirm the area affected by collapse.
2)-1 Countermeasures for the collapsed area
Following shear reinforcement and support reinforcement measures were taken to prevent the expansion of a large loosening area and plastic area.
- long steel pipe forepiling and long facebolt
-temporary upper half inverts and additional rock bolts
-primary invert with invert strut
2)-2 Measures for the ground ahead of the face
Through void investigation, interbedded clay soils with reduced ground strength were identified. Thus, following measures were taken for the crown, face and support reinforcement.
- long steel pipe forepiling and long facebolt
- primary invert with invert strut

Photo 2 Ground squeeze

3. Areas with thick layer of talus cone sediment

A talus cone sediment layer with an N value of less than 5 was about 10 m thick, filling the valley. To prevent deviation of earth pressure, excavation started after soil cement fill was placed. As the proportion of talus cone sediment in the face increased, it became difficult for the face to self-support. Long steel pipe forepiling and long facebolt were performed, but the injection pressure was not sufficient with less than the initial pressure of +0.5 MPa. Collapse occurred again, due to squeezing of the ground. Therefore, the grout management was changed so that the grout agent will have not only durability but also a ground improvement effect, and the injection amount was set to achieve the initial pressure of + 2.5 MPa.
Although this tunnel was built under difficult ground conditions, challenges were overcome by adopting a relatively versatile auxiliary tunneling method. We hope that this report will serve as a reference for future tunneling projects

Photo 3 Large collapse

Remote-Controlled Face Assessment by Digital Transformation

— Kanmuriyama Pass Road's 2nd Tunnel in Phase II —

Shinichi YAMADA ▸ Ministry of Land, Infrastructure, Transport and Tourism, Kinki Regional Development Bureau

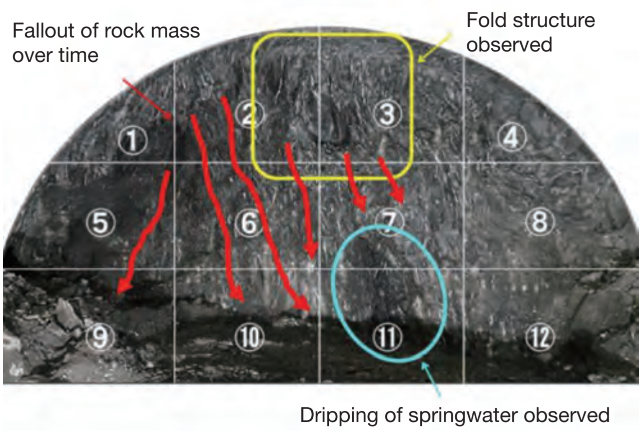
Kosuke KASHIHARA ▸ Managing Engineer, OBAYASHI CORPORATION

1. Outline of the Construction

During mountain tunnel construction, periodic "rock assessment meetings" are held between the contractors and contractees to determine the support pattern for subsequent cycles. The project of Kanmuriyama Pass Road's 2nd Tunnel in Phase II, saw sudden and frequent changes in the mountain conditions resulting in additional burdens on the parties involved with more meetings and suspensions of the construction. For operational efficiency, the contractors considered use of ICT tools and embarked on a trial project of remote observation.

2. Verifying the assessment system of remote observation

Prior to the trial, three raters were assigned to verify the difference and accuracy of the evaluation in the remote location and on site. Figure 1 and Table 1 show the face conditions and evaluation results. Conditions were rated on a scale of 1 to 5. Comparing the evaluation results between the remote location and on site, there was a ± 1 point difference in categories (A) to (G), but no tendencies were seen between the two locations, and the weighted average of the weighted scores was within 0.1. The results suggested that the accuracy of determining the support pattern can be ensured by the remote observation evaluation. However, to ensure validity, one of the three raters were assigned to make evaluations on site.



※ Information transferred from face to remote location

Fig. 1 Face evaluation results (photographic image)

Table 1 Face evaluation results (remote location and on site)

	Evaluation results in the remote location			Evaluation results on site		
Evaluation results by categories (ground condition and behavior at excavation point)	Rater A	B	C	a	b	c
(A) Face condition	222	211	222	221	111	221
(B) Excavation surface condition, unsupported	221	111	222	221	211	221
(C) Compression strength	332	222	222	222	222	222
(D) Alteration by weathering	221	222	222	222	222	221
(E) Crack frequency	332	322	233	332	332	332
(F) Crack condition	332	222	222	222	222	221
(G) Crack configuration	331	333	333	333	332	333
(H) Springwater	112	112	112	112	112	112
(I) Degradation by water	221	111	222	222	111	221
Weighted scores Weighted average scores	2.2	1.8	2.2	2.1	1.8	2.1

Entry in three digits Upper left (hundreds digits), Crown (ten digits), Upper right (ones digits),
Numbers in red : Score differences (+)

3. Full-scale trial of remote observation

For remote observation, a mobile terminal (i-Pad), a video call application (ZOOM) and a digital field notebook (eYACHO) were used to communicate with the on-site rater. Figure 2 shows the flowchart of the remote observation. The trial revealed the difficulty in recognizing in the images and videos of the bedrock the frequency and condition of fracture spacing, and the display of a scale on the screen of the terminal was suggested to make it easier to identify them at the remote location. The location of water inflow was also difficult to identify, requiring detailed explanations from the on-site workers.

Another issue was the means of communication with on-site workers. Even when the heavy equipment was stopped, conversations with all involved were difficult due to the noise of the blower and electrical equipment such as the electrostatic precipitator. After much trial and error, a self-build sound system with echo canceler function of car audio equipment was developed and utilized (Photo 1).

The remote observation of the "rock assessment meetings" was introduced during the excavation which coincided with COVID-19 pandemic, and this improved the productivity of future construction work and promoted work style reforms and digital transformation.

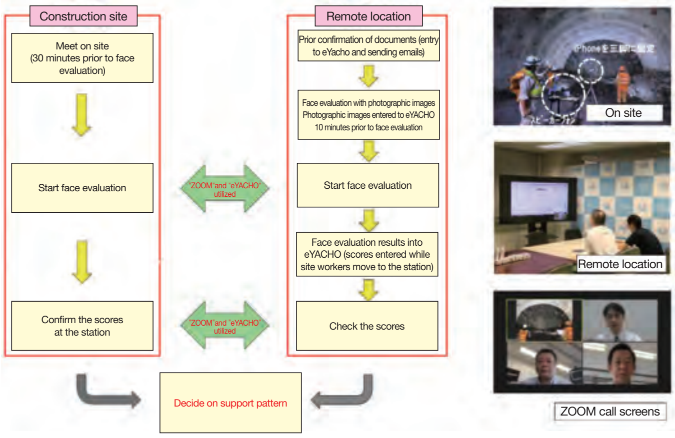


Fig. 2 Remote observation flowchart

Tunnel Construction through Ground with Landslide Potential Adjacent to the Median Tectonic Line with Various Countermeasures from Inside and Outside the Tunnel

—Matsuyama Expressway Myojinsan Tunnel Phase II —

Yusuke FUJII ▸ Construction Manager, Iyo Construction Section, Ehime Construction Office, Shikoku Regional Office, West Nippon Expressway Company Limited
Yusuke KINOMURA ▸ Construction Manager, Myojinsan Tunnel Construction Office, Shikoku Branch Office, Obayashi Corporation

1. Introduction

The Phase II line of the Myojinsan Tunnel on the Matsuyama Expressway is 2,545-meter long and was constructed as the second line of the in-service expressway. Its construction was performed under severe conditions and constantly required carefulness, where the in-service line was very close. In addition, the tunnel crosses the Median Tectonic Line near the exit, and the affected ground around the tunnel has geologically been subjected to substantial structural changes and exhibits its landslide potential (Figure 1). Furthermore, prefectural roads and houses are scattered on the above ground, making it essential to control the sliding of the ground and minimize its impact on the roads and houses as well as the in-service line. Therefore, stabilization measures and displacement measurements were carried out from both inside and outside the tunnel with the aim of controlling the impact of the tunnel excavation.

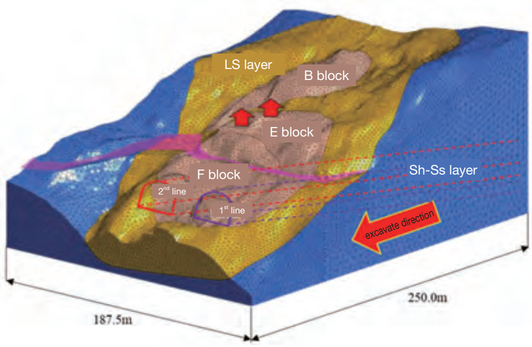


Fig. 1 Aerial view of the three-dimensional FEN model around the tunnel portals

2. Countermeasures from Outside the Tunnel

When excavating a tunnel through ground with landslide potential like this tunnel, it is necessary to perform landslide countermeasures from outside the tunnel before excavation to prevent landslides.
We employed 90 steel pipe piles (∅ 550, L = 30 m) as landslide control piles, as shown in Figure 2. In addition, in order to monitor landslide movement and ground surface displacement associated with the tunnel excavation, a number of measurement items were set up as shown in Figure 2, including three-dimensional automatic measurement using a total station. A large monitor was installed in our office for real-time monitoring of various measurement results and early detection of abnormalities. A system that clearly and constantly displays measurement graphs in a consolidated manner and automatically updates them was utilized to create an environment that facilitates the prompt identification of signs of abnormalities.

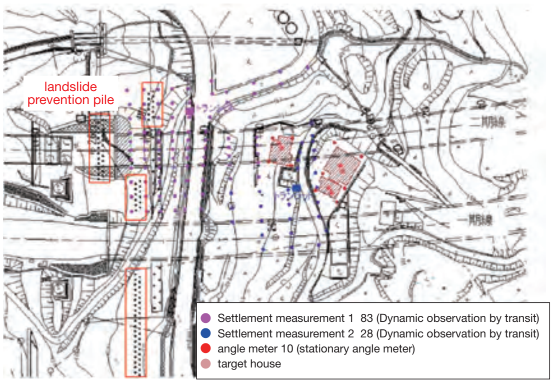


Fig. 2 Landslide countermeasures and measurement positions

3. Countermeasures against Poor Ground Conditions

The ground with landslide potential around the tunnel is composed of alternate layers of sandstone and shale. Folds and strong weathering were observed, and therefore, it was necessary to take measures to stabilize the cutting face so that they could cope with rapid changes in the ground. Because of the close proximity of the construction site to the in-service line, it was also necessary to take measures to control displacement as well. Therefore, we adopted long steel forepoling pipes (L = 12.5 m, 180° , ∅ 114.5 mm) and long face bolts (L = 13.5 m) as measures to stabilize the face, and constructed an upper half temporary invert as a displacement control measure as shown in Photo 1.

Photo 1 The temporary invert

4. Measurement Results

Figure 3 shows the results of Measurement A in the Phase II line construction. Although the final subsidence at the right shoulder showed a relatively large tendency of about 67 mm, it was within the management standard value of 119.7 mm and showed a trend of settlement in about 20 days after lower half and primary inverts were constructed. As a result, we confirmed that the tunnel construction was successfully completed without any impact on the surrounding area, based on the results of ground surface observation, measurement at various locations including the in-service line using underground displacement gauges, and visual inspections.

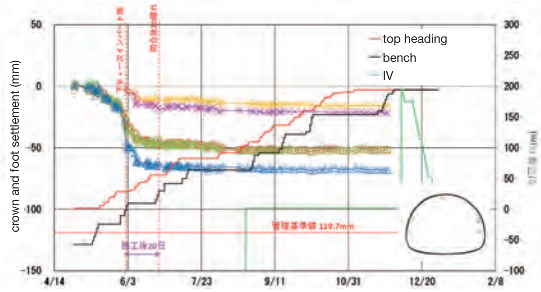


Fig. 3 LResults of the Measurement A

Rational Construction Work on the Fissured Ground by Utilizing ICT Technology

— Shin-Tomei Expressway Takatoriyama Tunnel West Construction Work —

Masahiro OKADA ▸ Hadano Construction Office, Tokyo Regional Branch, Central Nippon Expressway Company Limited
Kousuke KAKIMI ▸ Civil Engineering Division, SHIMIZU CORPORATION

1. Introduction

Shin-Tomei Expressway extends for approx. 253 km from Ebina City in Kanagawa Prefecture to Toyota City in Aichi Prefecture. Takatoriyama Tunnel West construction work covers the construction section on the west side of the mountain tunnel with inbound and outbound lines passing in an east-to-west direction through the southern foot of Tanzawa Mountains in Hadano City, Kanagawa Prefecture, and respectively extending for approx. 3,900 m. This construction section is located on the Hadano City side from the border of Hadano and Isehara cities.
The geological condition of this site mainly composed of tuff / tuff breccia with prominent fissures. Although the rock core in the fissured rock are relatively hard in nature, as the weathered cracks partially reach the rock core and they are open or with clay, collapsing of rock mass along the fragile crack surface were concerned. Thus, overbreak reduction by eliminating bumps on an excavation face affected by the heterogeneity of the ground and the crack properties has been identifed as the issue in this work.

2. Overbreak Reduction in Blasting Excavation of Fissured Rock

As a solution for this issue, we have jointly developed "BLAST MASTER", a system to reduce overbreak, with Sandvik K.K. and ENZAN KOUBOU Co., Ltd.
This technology provides a system which automatically controls / optimizes the insertion angles of outermost circumference holes (drilling angles) according to the size of overbreak occurred by blasting excavation. We have implemented this technology to Sandvik DT1131-JP Tunneling Jumbo as shown in the Figure-1. The overview of BLAST MASTER is as shown in the Figure-2. Repeating of this cycle several time will securely reduce overbreak.

3. Evaluation of the Effect of Overbreak Reduction

Regarding some sections (Cycle 1 ~ Cycle 11) where overbreak reduction effects were obtained, we have organized the average overbreak amount and variations in overbreak amount in chronological order. The results are as shown in the Figure-3.
Cycle 1 shows the result of blasting excavation by a blasting pattern (to be set according to previous experiences, ground strength, etc.) without insertion angle control. Cycle 2 shows the re-evaluated result of overbreak amount after automatic control of insertion angles according to the evaluation of overbreak amount in Cycle 1. These results confirm that repeating of insertion angle control each time after evaluating the overbreak amount can securely reduce overbreak step by step.
Cycle 9 has the least overbreak amount and the average overbreak amount was 5.0 cm. In the last Cycle 11, the average overbreak amount was 7.0 cm, achieving approx. 78% reduction in average from the initial overbreak amount. By securely reducing overbreak and smoothing the excavation surface through the application of this system to the fissured rock mass section, we have been able to prevent the expansion of loosening areas and secure the support stability, and completed the construction work safely without face accidents.

Fig. 1 Sandvik DT1131-JP Tunneling Jumbo

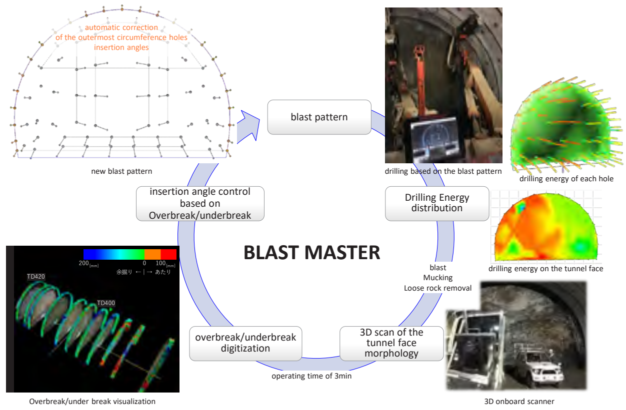


Fig. 2 Overview of BLAST MASTER

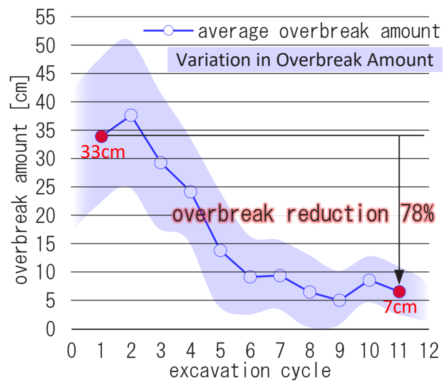


Fig. 3 Effects of overbreak reduction

Tunneling in the Fragile Ground with Low Competence Factor Affected by Faults

— Nakaoyama Tunnel —

Kazuhiro HASHIMOTO ▸ Yatsushiro Office of River and National Highway, Kyushu Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism
Shinya SHINGU ▸ Civil Engineering Div., Kumagai Gumi Co., Ltd.

1. Introduction

The Nakaoyama Tunnel is a 1,428-meters road tunnel of the Minami-Kyushu Expressway. Mt. Nakao has a geological structure composed of pyroclastic strata covered with andesite. As the competence factor is low due to a large overburden (maximum overburden: 250 m) on a soft ground, a massive plastic deformation has occurred. This report describes the measures to prevent displacement during tunneling work.

2. Occurred Phenomenon

Tunneling work was advanced while checking the ground conditions by conducting survey boring ahead of the face. However, due to a change in the geological features from around 250m point of the tunnel, pumice tuff and tuff accompanied by a fault, which is not assumed in the preliminary geological survey, appeared on the tunnel cross section (Photo 1).
As the displacement increased with the presence of these strata, breakage of rock bolts and cracks on the shotcrete became prominent. While the displacement proceeded even after the face separation exceeded 3D (D: tunnel diameter), the final displacement amount in the horizontal direction was over 180 mm.

3. Measures to Prevent Displacement

The original design for this tunnel set a three-stage pattern combining the steel support work and shotcrete (Table 1), however, the deformation of support and the increase in inner space displacement was not avoidable even with the highest-level pattern (DII-H2).
As a countermeasure, we provided early closure to establish a ring structure through early work (within 1D from face separation) with the invert strut and shotcrete (Figure 1). As a result, the status immediately inclined to convergence. Regarding the stress on support members, it was confirmed that compressive stress was applied to the entire ring and that the sufficient margin was secured for the yield of members.
After that, tunneling work was advanced while controlling displacement by early closure; however, the initial inner space displacement before the early closure increased due to the increased overburden (lowering of competence factor). We determined that the reason of this increase in displacement was lack of support pressure against the stress from the ground. Accordingly, we increased the member thickness by upgrading the support and improved the support pressure to restrain the inner space displacement until the cross-section closure. We adopted easily available common steel (NH200) for steel support work and shifted to the support pattern with increased support pressure by changing the shotcrete thickness from 200 mm to 250 mm. As a result, we successfully restrained the initial displacement and suppressed the increase of construction costs while ensuring stable construction at the same time.

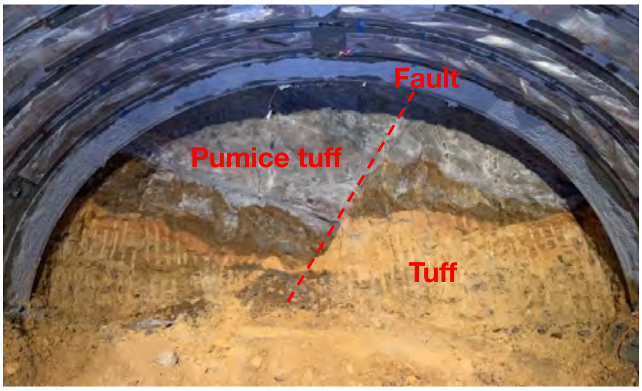


Photo 1 Occurrence of fault

Support pattern	Overburden (m)	Deformation margin (mm)	Shotcrete		Steel arch support work		Rock bolt		
			Strength (N/mm^2)	Shot thickness (cm)	Type	Installation interval (m)	Length (m)	Circumferential direction (m)	Extension direction (m)
DⅡ	56～112	100	18	20	NH-150	1.0	4.0	1.2	1.0
DⅡ-H1	112～200	100	18	20	HH-154	1.0	4.0	1.2	1.0
DⅡ-H2	200以上	100	36	20	HH-154	1.0	4.0	1.2	1.0

Table 1 Support pattern

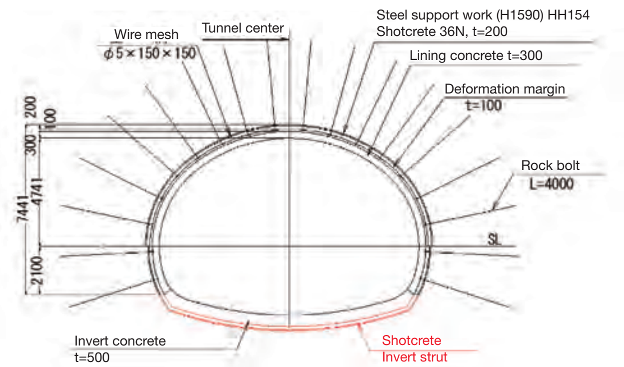
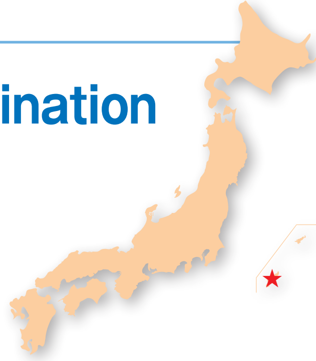


Fig. 1 Support pattern drawing



Addressing Hard Rock Grounds using a Combination of an Ultra-large Free-section Excavator and Controlled Blasting

Hirofumi NODA ▸ Project Manager, KUCHIYANAI Tunnel Project, Shikoku Branch Office, TOBISHIMA CORPORATION

Project outline

The Nago East Road aims to improve access between central and southern hubs such as Naha Airport and Naha Port, alleviate traffic congestion and improve traffic safety within Nago City, and support regional revitalization in the northern region. The Nago East Road No. 4 Tunnel is located nearest to the Naha City of the Nago East Road, with the length of 1,021 m that will reach the Sukuta region. Although the original plan was to use machinery excavation, at the start of construction, the ground turned out be harder than expected, so a blasting method was considered instead. However, since there were private houses dotted around the start tunnel portal and right above the tunnel route, the impacts of noise and vibration were of concern, leading to decision to excavate using a large machine using along with controlled blasting.

1. Problems that occurred while excavating hard rock grounds

During excavation using a free-section excavator (SLB-350S model), sandstone appeared in the phyllite at the face approximately 80m from the tunnel portal. This was an alternating layered structure with sandstone sandwiched between phyllites, and the strengths of the sandstone and phyllite were 101 MN/m2 and 37 MN/m2 respectively. Due to a large proportion of strong sandstone, the cycle time required for excavation increased, causing wear and tear on the bits in the excavator head and damage to the excavator itself, limiting tunnel excavation progress to about 2.4 m/day (Photo 1).

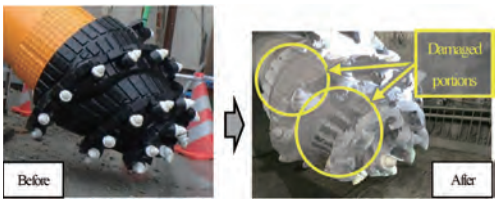


Photo 1 Damage to excavator head

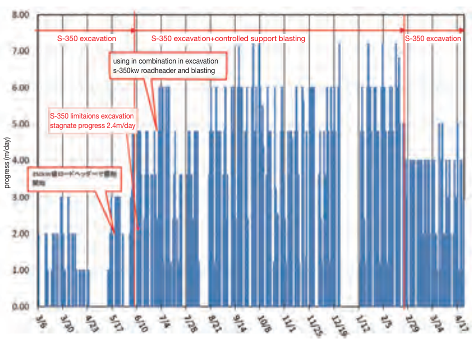
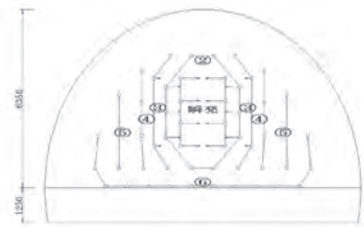


Fig. 1 Over-time change as excavation progresses

2. Machinery excavation along with controlled blasting

It turned out that excavation using a large machine caused delays in the construction process. The tunnel route was to pass through right beneath a village (minimum distance of approximately 40m from the tunnel center) and cattle sheds (minimum distance of approximately 40m from the tunnel center, with an earth cover of approximately 70m). Considering the geological and circumferential environmental conditions, it was decided to use controlled blasting in addition to machinery excavation in order to adhere to the construction schedule (Figure 2).



	cross section area	1 blasting progress length	fracture volume	boring number	number of holes drilled per ㎥	explosive usage	amount of explosive per ㎥
unit	㎡	m	㎥	hole	hole/㎥	kg	kg/㎥
top heading	63.3	1.2	76.0	56	0.9	44.8	0.59

Fig. 2 Controlled blasting plan for CII-b

3. Construction result

After chaging a construction method, the center of the face was cut by controlled blasting and the remains were removed by the excavator, reducing the excavation cycle time from 3 hr/m to 1.5 hr/m. Furthermore, the wear and tear on the excavator bits was reduced from 2.52 bits/m to 1.33 bits/m. As a result, a tunnel excavation progress of more than 4 m per day was achived (see Figure 1). In addition, both noise and vibration were below the standard values (noise: 85 dB, vibration: 0.1 kine), presenting no impact on neighboring residents and cattle sheds (Figure 3). The excavation using controlled blasting was completed approximately 130m before the end portal of the tunnel.

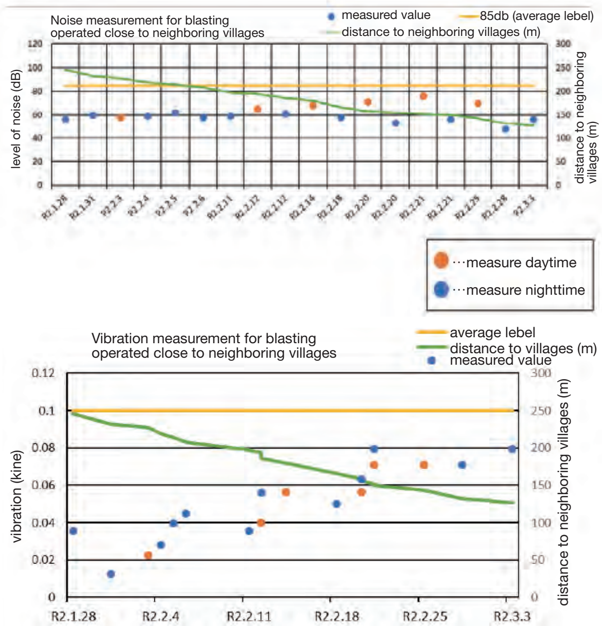
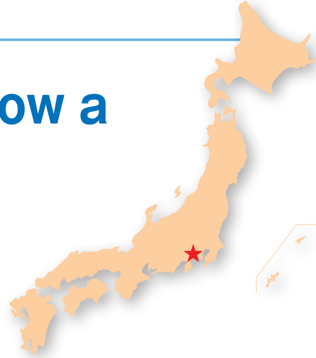


Fig. 3 Noise and vibration measurement for blasting operated close to neighboring villages



Tunneling Work on a Steep Slope Directly Below a Prefectural Road by Utilizing BIM

— Shin-Tomei Expressway Kayanuma Tunnel Construction Work —

Takuya TANAKA ▶ Central Nippon Expressway Company Limited
Junya TAKAMOTI ▶ Tokyo Regional Branch, SHIMIZU CORPORATION

1. Introduction

Shin-Tomei Expressway Kayanuma Tunnel constructed in this project crosses in an east-west direction between Hatano City and Matsuda Town; and extends for approx. 1,350 m (the inbound line of 1357.8m long and the outbound line of 1,350.6m long), and the inbound/outbound lines to be installed in parallel has new four lanes in total. The area surrounding the tunnel portal on the west side is configured by an old landslide terrain consisting of a fault fracture zone of Nakatsugawa fault system and a hydrothermal alteration zone; and Prefectural Road No.710, an important community road, passes directly above the tunnel portal. Thus, as several issues have been identified for the construction around the tunnel portal on the west side of Kayanuma Tunnel, we have utilized the three-dimensional BIM models and visualized the countermeasures (works inside the tunnel and for slopes) for construction work and planning and execution of works.

2. Utilization and Effects of BIM Models

(1) Planning of construction road

By repeatedly conducting field survey by a drone, we have created three-dimensional BIM models for the area around the west side tunnel portal area including construction roads. Creating of the three-dimensional BIM models as shown in the Figure-1, the following effects have been achieved:

1) Reduction of time for on-site measurement;
2) Sharing of final image to non-experts;
3) Improved understanding by workers through clarified work procedures;
4) Improved efficiency in soil volume calculation for cutting and banking;
5) Prior confirmation of slope gradient plan which is difficult to judge by a plan view;
6) Prior confirmation of finished cut oil in view of property border; and
7) Drafting of a safety equipment plan (taking into account of the road shoulder clearance to install a fall prevention fence on the top of slope).

(2) Planning of slope work and tunnel auxiliary construction method

The Figure-2 shows the three-dimensional BIM model for the slope work and the tunnel auxiliary construction method. This figure shows the three-dimensional model from the view point inside the ground. For example, in a conventional tunnel auxiliary construction method for tunnelling, reaching position for AGF and fore-piling driving position have been determined by a two-dimensional cross-sectional view or a plan view. On the other hand, by utilizing the three-dimensional BIM models, we could have made reasonable plans for countermeasures including verification of scope of application of countermeasures against circular slip on the surface layer of slope and tunnel auxiliary construction method, confirmation of the interaction between slope reinforcement and tunnel auxiliary construction method, etc.

3. Summary

By utilizing the three-dimensional BIM models, we have improved the efficiency of construction work, productivity of office work, and safety of construction work in the preliminary construction work and the main tunnel construction work. We expect that the models will be actively utilized in future tunnel construction works.

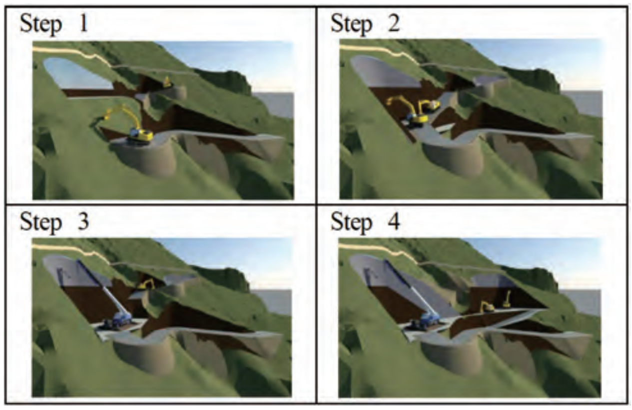


Fig. 1 Three-dimensional model of the construction road

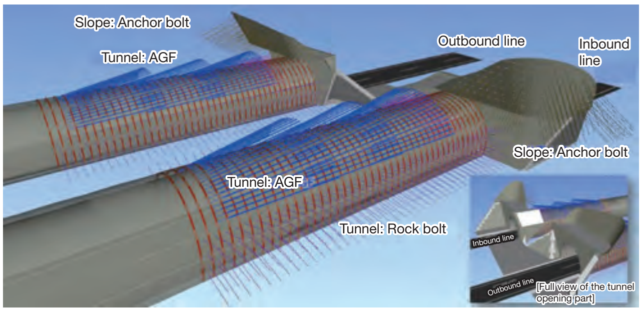


Fig. 2 Three-dimensional model of slope countermeasures and tunnel auxiliary construction method (showing the inside of the ground)

Photo 1 Tunneling for the inbound and outbound lines at the opening on the west side of tunnel

Started Large-section Shield Tunneling with Small Earth Covering of 1.1m

— Yokohama South Ring Expressway (Ken-O-Dou) Kuden-Kasama Tunnel —

Kenji MURATA ▶ Limited Construction Manager, Iwase Kasama Construction Section, Yokohama Construction Office, Kanto Branch, East Nippon Expressway Company

1. Introduction

“Kuden-Kasama Tunnel” on Yokohama South Ring Expressway is an annex tunnel whose total length is about 1.7km.
A shied machine with about 15m diameter leaves from a departure/arrival shaft to construct an outward tunnel first, turns within a rolling shaft, and restart to construct a return tunnel.
The earth covering ranges from about 1.1m-38.5m, and the shield machine starts where the earth covering is about 1.1m.

2. Geology Outline

The geology that this tunnel goes through consists of Kamifusa formation of Neogene-Pliocene to early Quaternary-Pleistocene.
The basement layer, called Ofuna formation, is a hard layer mainly made of mudstone, but at the start point of the shield machine with earth covering about 1.1m, there is soft alluvium (cohesive soil layer/organic soil layer) (Figure-1).
In addition, the groundwater level is high for the entire length of the tunnel; it is about 1 to 3m from the ground surface for about 70% of the 1.7km length of the tunnel, excluding hilly sections.

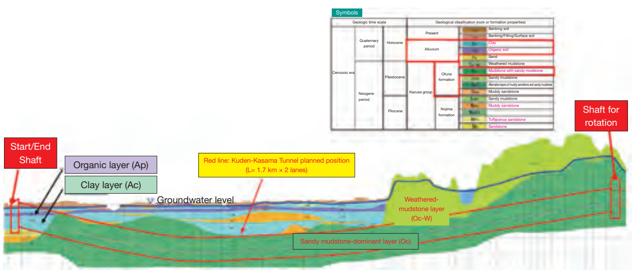


Fig. 1 Geologic cross-section map

3. Measures against Floating

In addition to the fact that the earth covering at the start point of the shield machine is small, since the groundwater level is high, measures against floating should be provided.
As the measures against floating, the surcharge load was increased by adding iron plates at the ground level, and the dead load was increased by adopting steel filled segments which are heavier the synthetic segments normally used for tunnel lining (Figure-2).
However, since those measures do not satisfy the given safety factor, steel ingots whose unit weight is larger than that of concrete were installed to the interior of the tunnel.
The shape and position of those ingots were designed not to interfere the passage of backup car, and were installable during the tunneling cycle using an erector for segment assembly (Figure-3).
Photo-1 shows the actual construction situation. The installation has been done as planned using the erector, the impact on the process was minimized.
In addition, the ingots were installed symmetry to prevent rolling, and no sing of rolling or floating has been observed during the post-installation form check.

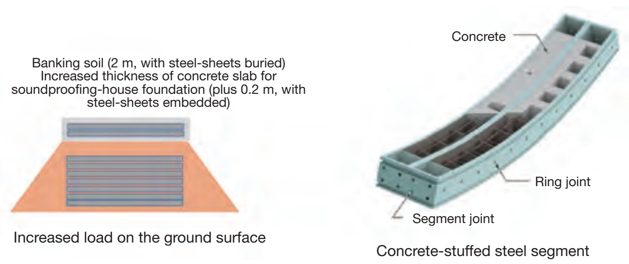


Fig. 2 Increase in load on the ground surface

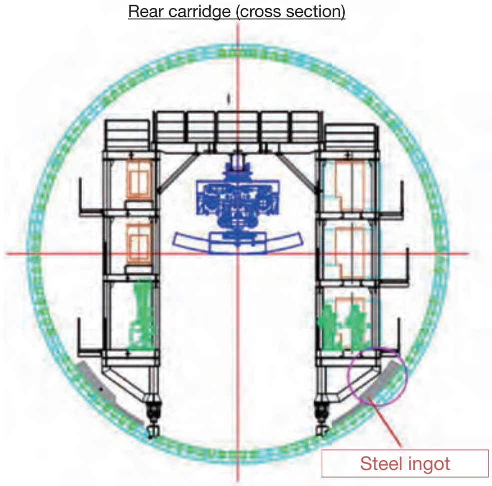


Fig. 3 Outline of steel ingot plan

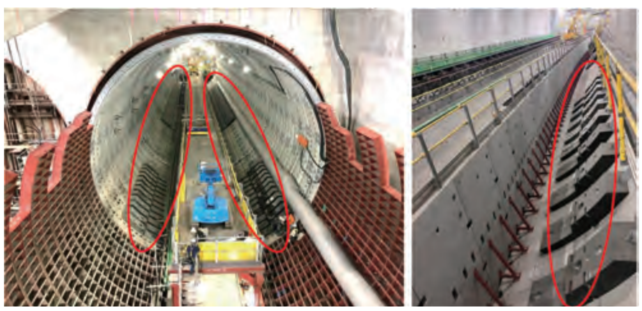


Photo 1 Steel ingot placement

Construction of Bypass Contributing to Environmental Protection of the Oirase Stream

— Environmentally Friendly Tunnel Construction in National Parks —

Nozomu TAKAHASHI ▸ Director of Kumano Second Tunnel Work Office, Nagoya Branch, Kumagai Gumi Co.,Ltd

1. Introduction

Lake Towada, which straddles Aomori and Akita Prefectures, and the 14 km-long Oirase Stream, which flows out of Lake Towada, are among the most scenic spots in Towada-Hachimantai National Park.

The Oirase Bypass is a road project designed to preserve the natural environment of the Oirase Stream and build a safe road (Fig. 1). There are numerous waterfalls in the Oirase Stream, and the bypass route was selected so as not to affect these waterfalls, and construction began with a tunnel section of approximately 4.6 km.

This paper reports on the efforts made in consideration of the surrounding environment during the construction of the tunnel in a specially protected area of the national park.

Fig. 1 Bypass location

2. Outline of the construction

In this work, an evacuation tunnel for the Aobuna-Yama Tunnel, which occupies a large part of the Oirase Bypass, was constructed with an excavation length of 4,573 m. The bedrocks were composed of lake sediments and tuff deposited by large-scale pyroclastic flows, and on top of these various ejecta from the Towada Volcano deposited and were generally loosely consolidated with abundant groundwater stagnated in the area, presenting concerns about sudden gushing water during tunnel excavation.

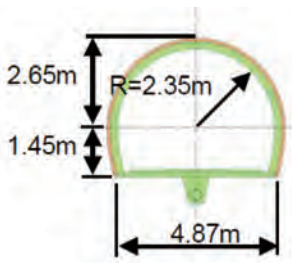


Fig. 2 Standard cross section

The evacuation tunnel has a small cross section (Fig. 2) and excavation was mainly carried out by mechanical excavation. Different excavators were used according to the geological conditions to ensure efficient excavation.

Drainage boring was incorporated into the construction cycle to check the geological conditions and prevent face collapse due to sudden water inflow. In implementing the drainage boring, groundwater level and waterfall flow rate were observed in real time to assess whether and to what extent the tunnel excavation would change the groundwater flows and affect the numerous waterfalls in the Oirase Stream. The maximum water flow rate from the drainage borehole was 800 l/min, and these springs were connected to the piping for clean water to separate the clean and polluted water. At the time of completion of drilling, the amount of fresh water treated from the drainage boreholes was approximately 35 m3/h, which accounted for 25% of the amount treated by the turbid water system (approximately 115 m3/h) in the aim to reduce the environmental impact on the Oirase River.

3. Adoption of environmental-friendly construction equipment

(1) Turbid water treatment facilities

Discharged water that was treated by the turbid water treatment facility and satisfied the discharge standards was discharged into the Oirase River downstream of the Oirase Stream via the environmental protection public sewage facility. Among the discharge standards for the discharge water, the amount of suspended solids was set to 40% (10 mg/ℓ) or less of the environmental standard at the outlet. As it was difficult to meet the discharge standard for suspended solids with the normal turbid water treatment system, a sand filtration system was added to the system. Another facility was added to return the treated water automatically to the raw water tank for reprocessing if the water in the final treatment tank exceeded the discharge standard (Photo.1).

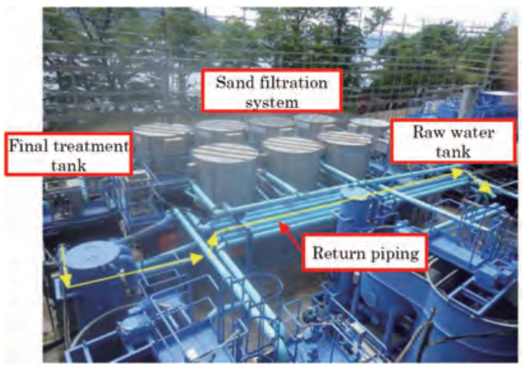


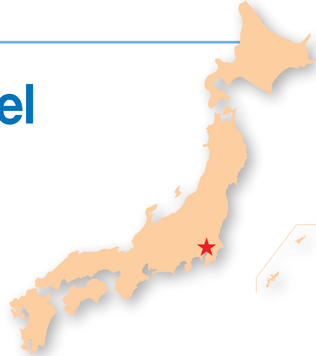
Photo 1 Turbid water system

(ii) Shotcrete

While shotcrete is generally used in a 'wet' method, there were concerns that the large amount of highly alkaline sewage would be discharged when washing the spraying plant, agitator trucks and spraying machines and might affect the environment. Instead, therefore, a 'dry' method, which does not require washing with water, was used to reduce environmental impacts on the discharge sites.

27

Overview of the Nihonbashi Underground Tunnel Project of the Metropolitan Expressway



Atsushi YABUMOTO ► Deputy Manager
Association: Nihonbashi Project Design Section, Renewal & Construction Bureau, Metropolitan Expressway Company Limited

1. Introduction

The structure of the Metropolitan Expressway over the Nihombashi River was built before the 1964 Tokyo Olympics and more than half a century has passed since its opening. The severe use of the Nihonbashi section of the expressway, with approximately 100,000 vehicles per day, has resulted in severe damage to the structure, necessitating drastic countermeasures. Therefore, a large-scale renewal project was prepared to replace the existing viaduct with a tunnel structure. In this project, the tunnel is to be constructed underground under many constraints, such as the fact that the construction is linked to several redevelopment projects in the surrounding area. The subsequent removal of the existing viaduct will improve the appearance of the Nihonbashi area and enhance the attractiveness of the area (Fig. 1). The underground route is scheduled to open in 2035 and the viaduct to be removed in 2040.

2. Outline of the structure of the Nihonbashi Underground Tunnel

In order to minimize the impact on the ground surface, the structure was selected based on the shield tunneling method, which is non-open-cut and has a good track record as a construction method for road tunnels. The section connecting to the existing Yaesu Tunnel is to be constructed using an open-cut tunnel structure (Fig. 2).
The launching shaft for the shield tunnel is to be installed near the Edobashi Bridge, which was the only place where the backyard necessary for construction could be secured, and the tunnel will be launched with a small earth cover. In order to reduce costs, the shield machine will be rotated after reaching the shaft near the Ichikokubashi Bridge, and the same shield machine will be used to excavate to the launching shaft. Evacuation passageways in the tunnel will be installed under the slab from an economic point of view. Other equipment spaces, including smoke ducts and inspection passages, will also be installed under the floor slab. The shield tunnel has a small earth cover, steep curves and steep gradients, and many redevelopment buildings are constructed right above the tunnels. Composite segments have been adopted for the lining of all lines, taking into account the overburden load of up to 200 kN/m^2 , the small earth cover, the seismic effect and the risk of damage during construction due to the curve shape. No secondary lining will be installed to reduce construction costs by reducing the cross section. While ground improvement in the surrounding area and the use of weight-added members are possible measures to prevent lifting, in consideration of the project process, the segments made of fire-resistant heavy concrete have been adopted to provide the necessary weight.
It is required that the water level is not raised above that of the existing river channel due to in-river works on the Nihonbashi River. As the surrounding area is a redevelopment project site and land acquisitions are difficult, measures to prevent water level rise by widening the river channel can only be implemented to a limited extent.

Therefore, the construction of an open-cut tunnel right under the river is planned to adopt a riverbed protection structure that separates the space where the tunnel is constructed from the river (Fig. 3). Boards will be installed in the river to replace the riverbed and prevent the river water from entering the tunnel construction space. This avoids the reduction in a cross-sectional area of the river due to river closures, etc. A double watertight structure will be installed at the joints between the boards and at the edges of them to ensure reliable watertightness.

Fig. 1 Images of the area around the Nihonbashi Bridge after the viaduct has been removed

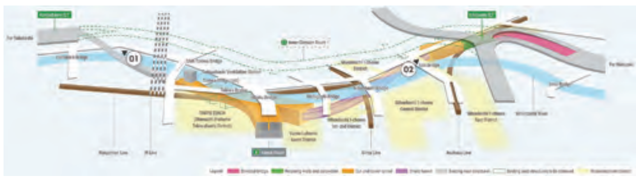


Fig. 2 Diagram of the Nihonbashi underground route

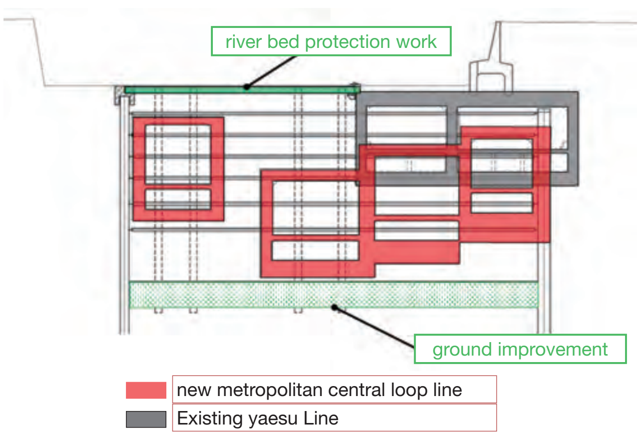
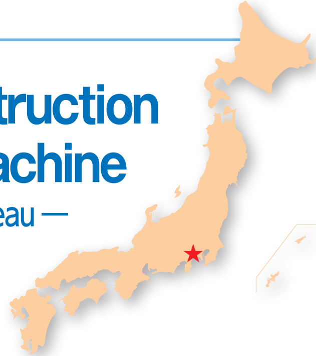


Fig. 3 Schematic diagram of construction right under the river

Improved Safety and Productivity in Tunnel Construction Work through Utilization of a Rock Bolt Driving Machine

— Construction Work for the Kiyo No.3 Tunnel of Chugoku Regional Development Bureau —



1. Introduction

In order to secure the safety of rock bolt driving in mountain tunnel construction works, we have jointly developed “BOLTINGER”, an automatic rock bolt driving machine as shown in the Figure 1, with Furukawa Rock Drill Co., Ltd. As the construction work for the Kiyo No.3 Tunnel of Chugoku Regional Development Bureau is designed to drive 6m rock bolts for the entire line, BOLTINGER has been deployed to save labor, improve safety, and speed up the cycles of rock bolt driving.

Fig. 1 “BOLTINGER”, a special driving machine for rock bolts (with 2 booms and 2 baskets)

2. Characteristics of BOLTINGER

This machine has the following three characteristics:

(1) A mortar feeder integrated to the rock bolt driving machine to save labor for ground work;

(2) A guidance function for drilling work to improve the productivity in rock bolt driving work; and

(3) Obtaining of various data during drilling and understanding of information on the ground to realize safe work.

The Kiyo No.3 Tunnel is a fragile large-section tunnel with an excavation cross-sectional area of over 120 m2. As shown in the joint bolt specifications in the Figure 2, the aforementioned 6m rock bolts have been driven for the entire line. BOLTINGER has saved the labor for driving these rock bolts that are longer than the regular ones and improved the productivity and the construction speed.

3. Rock Bolt Driving by BOLTINGER

In the rock bolt driving work by BOLTINGER, a driving hole is drilled first by the drilling boom. After drilling, the boom position of the driving device is determined; mortar is automatically filled as shown in the Figure 3; and then, bolt insertion (including for uniting only) is performed. As the magazine can keep ten 3m bolts, bolts are loaded to the magazine by the lower part of boom each time after five 6m rock bolts are driven.

Fig. 2 6m joint rock bolt

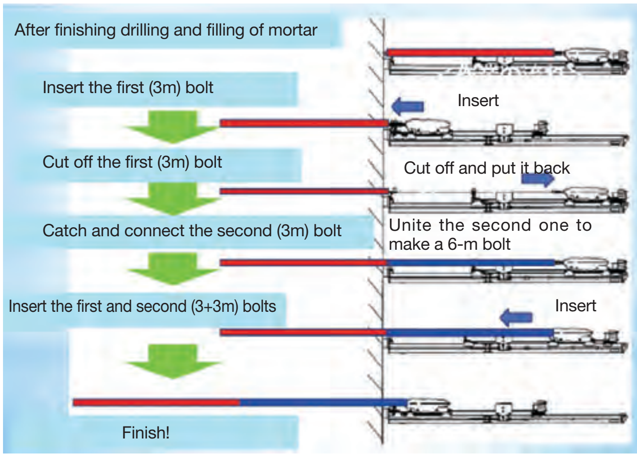


Fig. 3 Rock bolt driving sequence

4. Evaluation on BOLTINGER

Workers have highly rated the usability of BOLTINGER in general. As driving of 6m rock bolts is a tough work, use of machine for this work is beneficial. On the other hand, this machine has three booms; however, one of them is dedicated to rock bolt driving, which means that the actual construction performance just equals to that of 2-boom jumbo. Therefore, it is necessary to improve the operation methods to ensure higher cycle performance and improved construction speed by implementing preboring of face in an idle time or other appropriate measures while ensuring efficient rock bolt driving.

Design and Construction Status of Raw Water Transmission Facilities in the Omoi River Development Project

— Kurokawa Canal Tunnel, Oashi River Canal Tunnel, Water Conveyance Channel Tunnel —

Naoki MORIHARA ▶ Chief, Design Division, Dam Project Dept., Japan Water Agency

1. Introduction

The Omoi River development project is a multi-purpose dam project currently implemented in Kanuma City, Tochigi Prefecture, by Japan Water Agency. Construction of Nanma Dam on the Nanma River, a tributary of Omoi River of Tone River system, and installation of adjacent raw water transmission facilities between the Kurokawa River / the Oashi River (tributaries of the same river) and the Nanma Dam reservoir, will establish efficient water resource development which enables raw water transmission outside the basin to the dam reservoir as well as water interchange between tributary basins. The maximum raw water transmission from the Kurokawa River / the Ooashi River to the dam reservoir is 20m^3/s; and the maximum water conveyance from the dam reservoir to the Kurokawa River / the Oashi River is 4.6m^3/s.

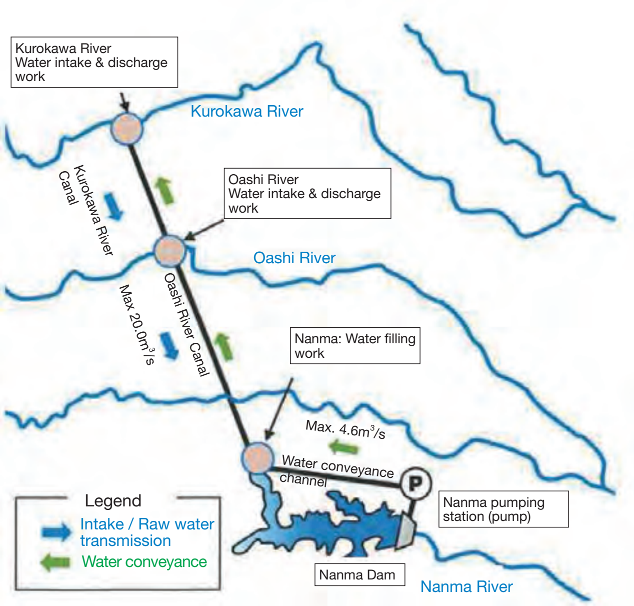


Fig. 1 Overview of the facilities for the Omoi River development project

2. Design and Construction of Raw Water Transmission facilities

(1) Canals

Photo 1 Slurry shield machine

The canal tunnel extends for approx. 8.6 km, with two types of inner diameter: 2.3 m and 2.8 m, and largely passes through mountain areas. The largest overburden from the ground is 495m; and external water pressure up to about 3.8 MPa is applied to the tunnel structure during construction and after completion. In the surrounding areas, mountain stream water and groundwater is used as domestic water. Therefore, to minimize the impact of the canal tunnel on the water use, the tunnel structure after completion has been designed to be completely waterproof against the applied pressure. Furthermore, we have adopted "the slurry shield method" which enables a certain level of waterproof during the construction (Photo 1). A total of three shield machines, having pressure tightness up to approx. 2.4 Mpa which is the highest level in Japan, have been used.

(2) Water conveyance channel

The water conveyance channel extends for approx. 4.2km, with the inner diameter of 1.9 m, and passes through the mountain areas; however there is no water use in the surrounding areas, and therefore "the open-face shield method (double shield type)" allowing a high construction speed has been adopted.

3. Conclusion

Since the inner diameters of canals and water conveyance channel are small, construction has been conducted by the smallest drilling diameter which is close to the limit for tunnelling work by the shield method and the open-face shield method. We will continue to proceed with construction in a safe and secure manner.

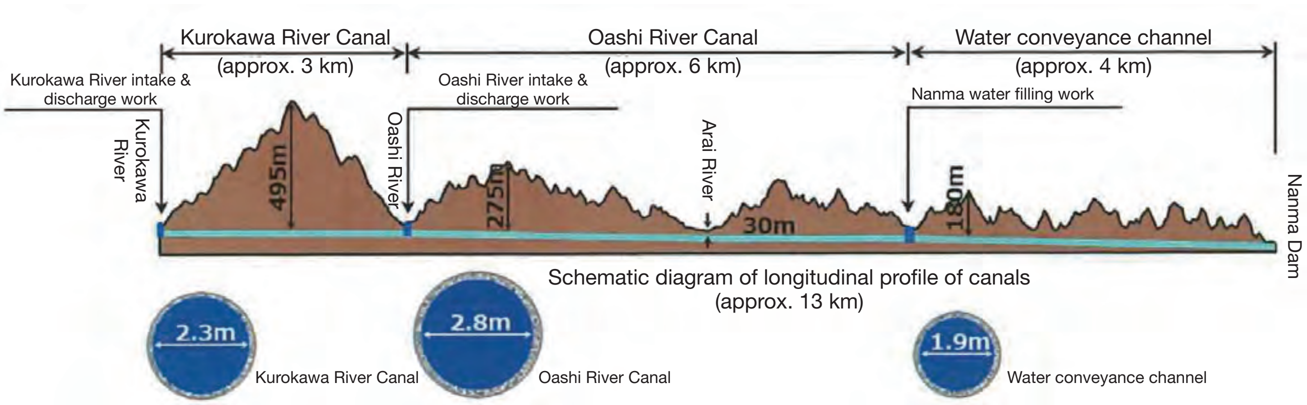


Fig. 2 Longitudinal view of the raw water transmission facilities

Implementation of Long Slurry Shield Method in Complex Soil and Vicinity of Important Constructions such as Shinkansen

— Osaka City Construction Bureau Osumi to 18-jo Sewage Waterway —

Katsumi MOCHIHARA ▶ Osaka City Construction Bureau
Koji KAYUKAWA ▶ Civil & Structural Engineering Department, HAZAMA ANDO CORPORATION
Koji TORIYAMA ▶ Okazaki Shield Office, HAZAMA ANDO CORPORATION

1. Introduction

Osaka City is constructing a facility that can handle heavy rainfall of 60mm per hour, which generally occurs once in every 10 years in the northern part of the city. This facility is a sewage waterway with a maximum inner diameter of 7,500mm and a total length of 22.5km.

This project is a part of the trunk sewer, and a sewer culvert with outer diameter of 5.85m and inner diameter of 5.25m is constructed for the approx. 4,080m section by the slurry shield method.

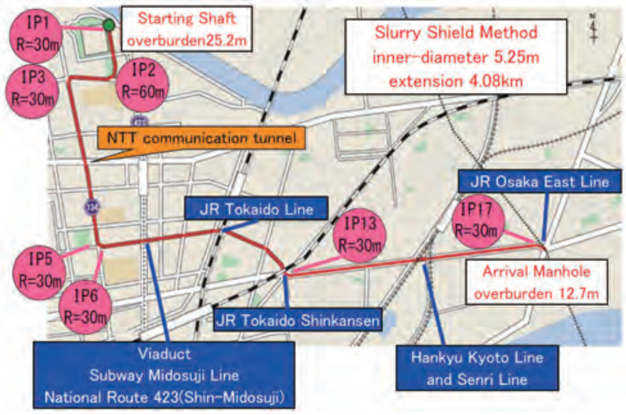


Fig. 1 Route Plan

2. Alignment

Figure-1 shows the plan view of the line. The line is a 4,080m long line that passes through a watershed which would be connected with existing sewer facilities, and there are a total of 17 curved sections ranging from R=30m to R=500m.

3. Geology and Response to Adjacent Structures

Figure 2 shows a vertical geological profile. The area is located at the source of river flooding and alluvium consisting of soft clay, sand, and gravel are distributed. The geology for the first half of the line is consisting of the Osaka Group (Oc, Os, Og) to Tenma Gravels (Tg maximum gravel diameter ϕ 150mm), which contains sand and gravel. The latter half of the line is Alluvium consisting of loose sand (As), sand and gravel (Asg) and clay (Ac) layers with N values of 3 to 7. Especially in the shield tunneling of the Alluvium in the latter half, the quality of the slurry was thoroughly controlled paying special attention to its gravity and viscosity to ensure the stability of the face.

In addition to railways, there are a number of roads and sewage processing facilities in the vicinity of the line. Figure-3 shows an example. As a countermeasure, a trial construction, automatic measurements, limiting the time of passage, and, on the Hankyu Line (Kyoto Line and Senri Line), protective improvements by inclined drilling from outside the track were implemented.

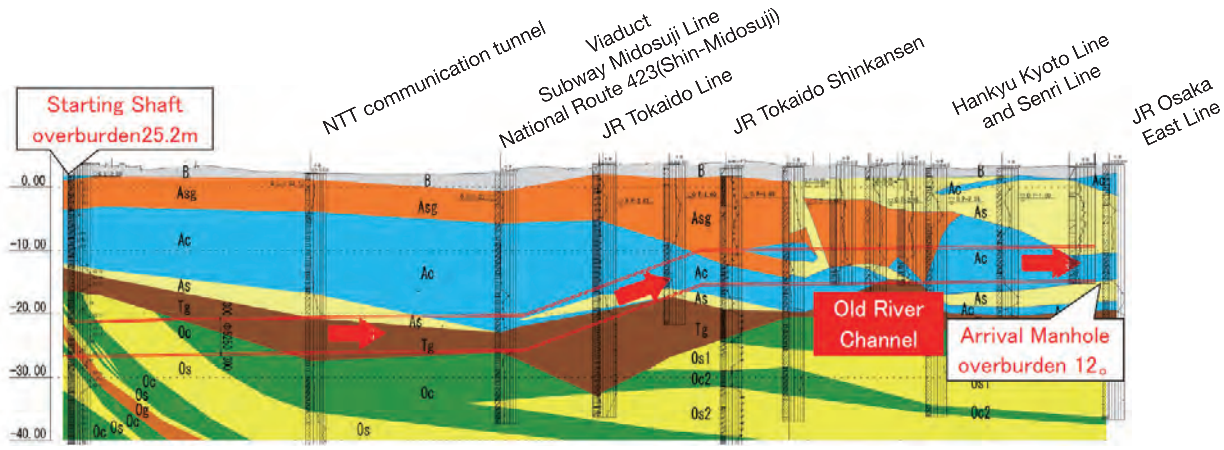


Fig. 2 Geological Longitudinal Map

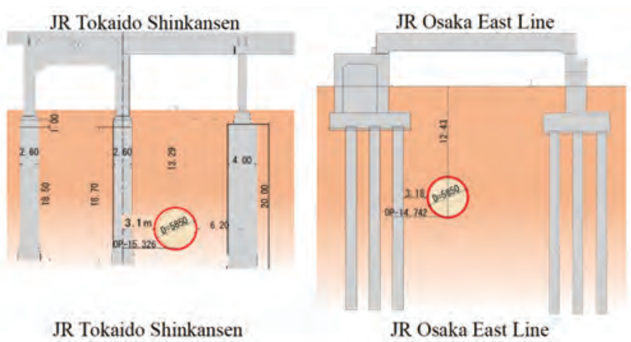


Fig. 3 Situation of Neighboring Construction

4. Summary

This project was a long construction project of approximately 4 km with many sharp curves. Because of the soft ground in the latter half of the line, measures to prevent ground deformation and ground settlement during shield excavation were taken, and detailed plan and measures were provided for construction close to existing structures in service, such as railroads. Although there were some problems during the construction, such as water inflow and lost circulation, measures had been taken flexibly to various events, and the construction has been completed successfully.

Long Tunnel Constructed by Excavating Extra-small Cross-section by NATM Method with Rail System the NATM Rail Method

— Seinaiji Hydroelectric Power Station Headrace Tunnel —

Masatoshi ONO ▸ Office Manager, Seinaiji Construction Office, MAEDA CORPORATION

1. Introduction

The headrace tunnel (Photo 1) for a run-of-the-river hydraulic plant being constructed by Chubu Electric Power Co., is a tunnel with an extra-small inner space cross-section of B=2.4m x H=2.55m (about 6m2).
As the geology is mainly solid granite, two tunnels of 2751m and 2396m lengths were constructed by NATM method. The geology is mainly solid granite.

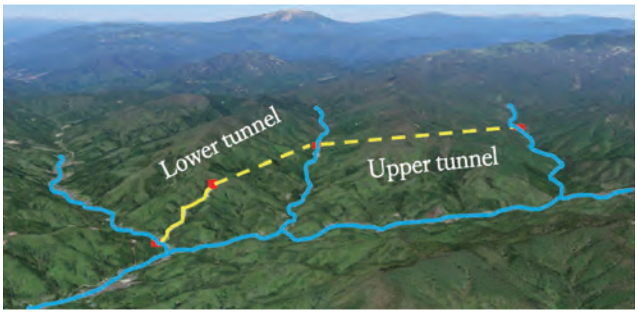


Photo 1

In order to construct 2 tunnels at a time, a batcher plant, muck dumping site, temporary facility yard for lifting equipment etc., and railyard were combined in one location. Construction machine configuration consisting of (1) drill jumbo, (2) shaft loader for muck loading/shuttle car for transport, (3) spraying robot were used to a series of works of excavating, bringing out muck, and spraying concrete (Figure 2).

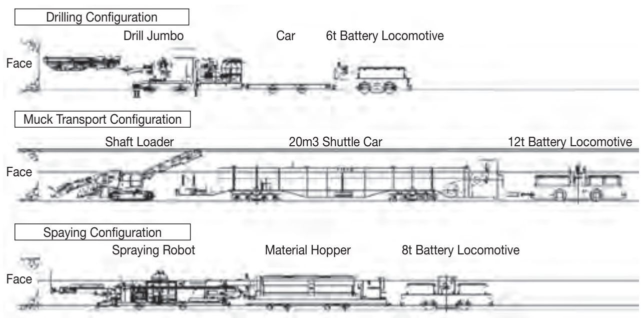


Fig. 2 Tunneling Machine Configuration

2. Tunnel Planning and Construction Method (adoption of rail system)

The cross section of the tunnel is designed with the minimum cross-section area possible aiming at reducing the construction cost while maintaining the functions as a headrace. The rail system with battery car towing, was adopted considering that the tunnel is long distance with extra-small cross-section area and the deterioration of the underground environment caused by exhaust gas. In order to improve the efficiency for the long-distance construction, widening for passing and widened section for temporary facilities were provided every 900m and 300m respectively. The maximum excavation progress per month was 130m, and the average was CL-class 2.9m/day, CM-class 5.1/day, and CH-class 5.7m/day (Figure 1).

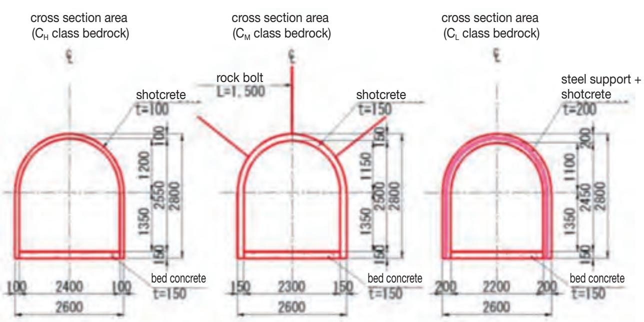


Fig. 1 Supporting Pattern

3. Safety/Work Environment Measures

Due to the extra-small cross-section area, safety assurance for workers was the most important issue. By installing sensing transmitters cars on rail, an alert and warning light installed at the nearest pull-in was activated to notify workers in the tunnel that a car is approaching. In addition, other measures, such as installing automatic breaking with magnetic sensors for cars, were taken to ensure workers' safety, and achieved penetration without accident. As for the working environment measures, since the extra-small cross section made it difficult to install large ventilation equipment, Φ 300 windpipes and liquid quick setting admixture in shotcrete were used to reduce the dust concentration.

4. Conclusion

Although there were only a few recent records and people with experience, the NATM method with rail system for extra-small cross-section area has been completed without accident or disaster thanks to improvements and innovations.

Construction of Long-distance Headrace by an Open-Type TBM with Maximum Monthly Advance of 678 m

— Mitsubishi Materials Komatagawa New Power Plant —

Koichi HIRAISHI ▸ General Manager,
Mitsubishi Materials Corporation, Strategic Headquarters

1. Introduction

Construction of the Komatagawa New Power Plant was commenced in April 2019 and completed in December 2022. Water is directly taken from the outlet of the Komatagawa No.4 Power Plant directly under Moriyoshi Dam and led to the downstream new power plant which secures an effective head of 91.5 m and maximum output of 10,326kW and generates approx. 48,500 MWh per year (Photo-1). The total length of headrace tunnel is 8,492.1m; and the channel gradient is 1/1210 ~ 1/1300. With an access to the second construction section for TBM from the horizontal working adit (2), construction of the section extending for 7,658.4 m was executed by TBM (Fig. 1).

Photo 1 Full view of the hydraulic power plant

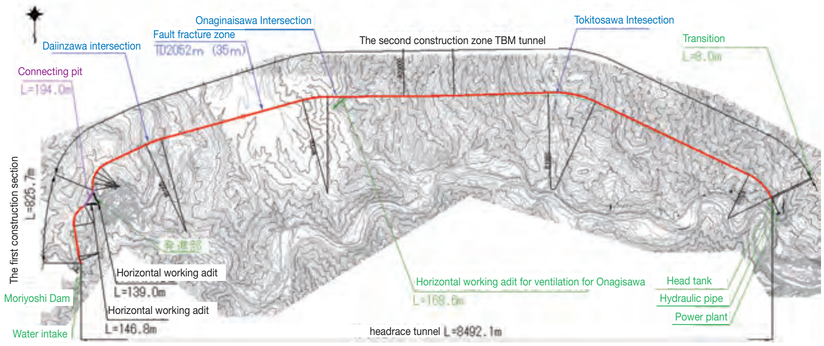


Fig. 1 Plan view of the Komatagawa New Power Plant

2. Headrace Tunnel Plan

We have designed a ϕ 3.52m open-type TBM equipped with 24 17-inches disk cutters (Photo-2). The TBM is assembled in a temporary yard, drawn to the TBM starting place, and executes initial tunneling for a total of 60 m. We have adopted continuous belt conveyors and installed booster drives at two places in the tunnel to secure the mucking capacity of 230t/h. For materials and equipment transportation, we have established separation points at two places in the tunnel to avoid waiting time for materials and equipment.

At the reaching point on the head tank side of the power plant, a transition with a total length of 8.0 m is drilled to pass through this point. The TBM is disassembled inside the tunnel and carried out through the horizontal working adit (2).

The TBM small cross-sectional tunnel support use PF mortar shot (f'ck = 36N/mm^2) and steel ring support (H-100) as the main support members, and the standard support pattern using the combination of these members is used (Fig. 2, Photo-3). Bottom concrete plates use invert blocks (f'ck=18N/mm^2); and they are installed before the following dollies and single-track rails are fixed on them. For lining, fiber reinforced shotcrete lining (f'ck = 18N/mm^2) is used and the lining work is executed after the completion of TBM tunneling work. The ground is composed of tuff breccia, tuffaceous mudstone, dolerite and andesite. The maximum overburden height is 161 m.

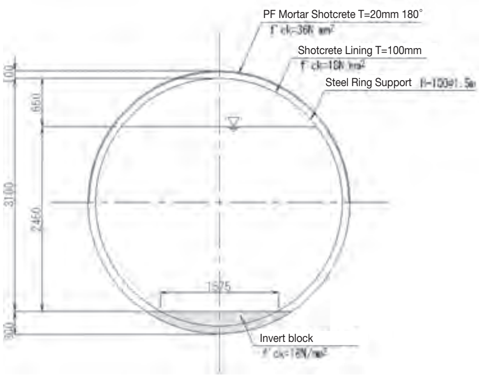


Fig. 2 Example of tunnel structure (Support type C)

Photo 2 External view of the Φ3.52m Open-type TBM

Photo 3 Full view inside the TBM tunnel (support type B1)

3. Results of TBM Tunnel Construction

TBM tunneling was started on January 13, 2020 and completed on August 24, 2021. The tunnel penetration accuracy was a deviation of + 53 mm in the vertically upward direction and - 140 mm to the left in the horizontal direction. The maximum daily advance was 64 m; the maximum monthly advance was 677.5 m; and the average monthly advance was 382.9 m, exceeding the planned monthly advance of 347 m. The operating rate per total work days was 71.5%. It required 20 months for headrace tunnel excavation; 7.5 months for shot lining by dry spray method with the average monthly advance of 1,094 m; and 2 months for removal of temporary equipment, and it took 34 months to complete the headrace tunnel construction work.

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Development and Implementation of Automated Construction Techniques Around the Tunnel Face

Yoshinori KITAMURA ► KAJIMA CORPORATION

Aiming to make all work around the tunnel face (which is accompanied by high risk of accidents such as collapse) during construction of mountain tunnels unmanned, KAJIMA is promoting the automation of all such work by adopting A4CSEL. A4CSEL (pronounced "quad-accel") is a next-generation construction production system with automatic operation of construction machinery at its core. A4CSEL is based on the concept of operating multiple automated construction machines with few workers in a manner that assures to construction work is performed effectively and safely.

In order to improve safety, productivity, and quality in mountain tunneling, "A4CSEL for Tunnels" automates the six construction steps involved in excavation work for constructing mountain tunnels. It thereby enables efficient, unmanned work at the tunnel face which until now have relied on skilled workers.

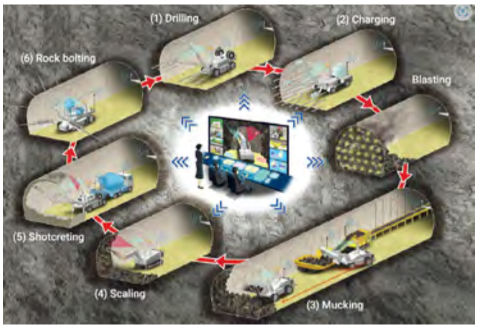

Fig. 1 Kajima's concept of "A4CSEL for Tunnels"

We had succeeded in mucking work with an automated wheel loader and shotcreting work with an automated machine by the year 2021.

Fig. 2 Automated shotcreting machine

Fig. 3 Automated wheel loader

To demonstrate the blasting planning technology developed to accomplish "blasting excavation without overbreak" and many other automation technologies developed to date in an environment equivalent to that of an actual construction site, we are trying an industry first by actual excavation of a test tunnel. Through demonstration tests in the field, we aim to automate the six steps in tunneling, namely, drilling, explosives loading/blasting, mucking, scaling, shotcreting, and rock bolting, to achieve unmanned operation around the tunnel face. In this way, we will establish a construction system that achieves a high degree of both safety and productivity by enabling optimal automatic operation.

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Slide Loader™: Special Bucket for Safety and Productivity in Muck Loading

—Improved Operability for Remote and Automated Control—

Takashi SUGIMOTO ► Construction Engineering Section,
Construction Engineering Department 1,
Construction Robotics Division,
Obayashi Corporation

1. Overview

The surplus soil from tunnel excavation is removed by a transport vehicle using a wheel loader. They are placed next to each other and the bucket of the loader is tilted for the soil to be loaded to the transport vehicle. This conventional method, called "side dump bucket mechanism," requires sufficient space above the bucket and skilled techniques of the operator to avoid contact with the ventilation equipment or lighting. The newly developed Slide Loader™ enables easier and space-saving loading of the soil by moving the blade installed in the bucket horizontally in the discharge direction. (Photo-1)

Photo 1 Wheel loader equipped with Slide Loader™

2. Improved productivity using a larger machine

Compared to the "side dump bucket mechanism," Slide Loader™ enables soil dumping at a lower position with a larger and higher-performance machine than the regular wheel loader. The increase in the bucket capacity results in less loading time, reduced by about 30% (tested results by Obayashi Corporation). (Figure-1, Figure-2)

3. Improved operability

While the "side dump bucket mechanism" requires the operator to avoid contact with the surrounding equipment, with the simple operating mechanism of Slide Loader™, the risk of contact damage is reduced and skilled operators are no longer needed, helping solve the problem of a shortage of skilled workers. Obayashi Corporation aims to remote and automate the loading operation with further verification of the Slide Loader™.

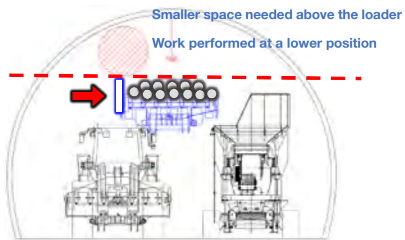

Fig.1 Loading by Slide Loader™

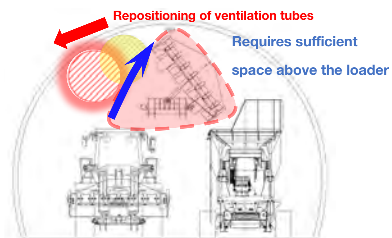

Fig.2 Loading by "side dump bucket mechanism"

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Haka-router®: A Wireless Strain Measurement System of Steel Supports

Daisuke FUJIOKA ▶ Deputy Manager, Geotechnical Engineering Department, Technology Research Institute, Obayashi Corporation
Kenichi NAKAOKA ▶ Chief Engineer, Geotechnical Engineering Department, Technology Research Institute, Obayashi Corporation

Haka-router® wirelessly measures the strain of steel supports. It wirelessly transmits strain measurement data, monitors it in real time and alerts face workers of danger when stress increases. Following are the features of this system:

1) Setting the threshold value for stress allows the system to alert face workers of danger with sound and light when stress exceeds the value. The system is useful for stress measurement of not only steel supports, but also shotcrete stress and rock bolt axial force.
2) Since the transmitter is attached to the steel support outside the tunnel, such as in the material yard, there is no hazardous wiring work at the face of the tunnel or delay in the excavation work. The transmitter's base is covered with resin and the body is covered by a steel protector to withstand the vibrations of tunnel works, blast waves and vibrations caused by blasting, and spring water. The transmitter lasts for about 1.5 months, the time needed for the tunnel's displacement convergence, and it can be reused by recharging the battery.
3) The receiver, alarm lights, and tablet PC for measurement are installed as a set in the tunnel, and the distance between the transmitter and receiver can be up to 50 meters, thus the measured values can be remotely monitored.

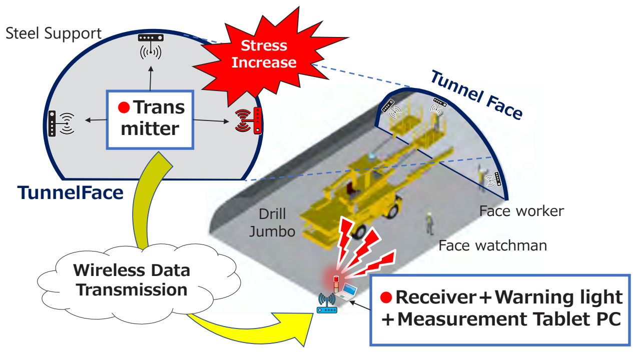

Fig. 1 Haka-router® device configuration

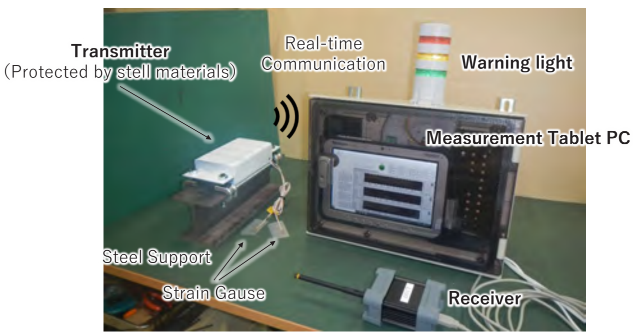

Fig. 2 Haka-router® device set

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Remote Operation Using Double-boom Rock Bolt Machine

Yasuo IDE ▶ Group Manager, Civil Engineering Technology Division, Underground Section, Shimizu Corporation

The "Remote Rock Bolt Installation System" that mechanizes rock bolting process consists of a double-boom rock bolting machine and an automatic mortar feeding system; a technology that enables seamless operation of a series of work processes from rock bolt drilling to rock bolt insertion in accordance with the high-precision navigation.
The bolting unit (Figure-2) is comprising a drilling equipment (with HD210S drifter), a motor feeder, a rock bolt magazine (stores 9 bolts), and a rock bolt ejector (with HD30 drifter), and the system has a total of 2 bolting units.
The large-size automatic motor feeder is controlled by a level sensor and a timer, and depending on the mortar consumption, it can automatically feed 2 motor pumps for left/right boom with mortar at the maximum speed of 84.8kg/min.
The finished shape of rock bolts and the amount of mortar charge are displayed on the control panel for monitoring and stored automatically in the database. Mechanization of rock boiling enables to shorten excavation cycle time, improve work safety, construction quality, and accuracy of finished shape, and thus, significant improvement of productivity is expected.

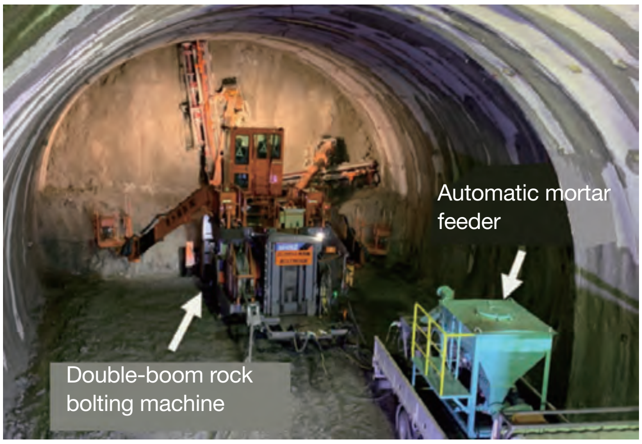

Fig. 1 Remote Rock Bolt Installation System

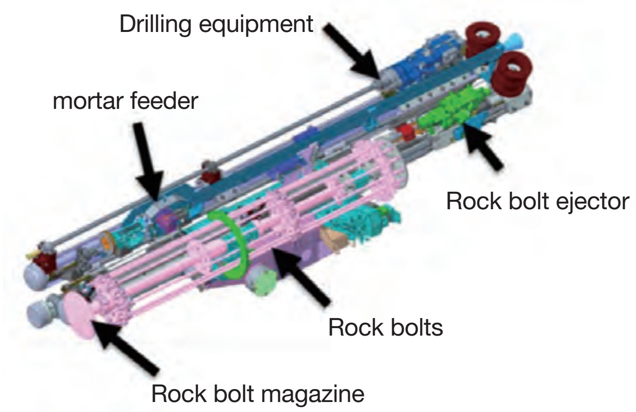

Fig. 2 Bolting Unit

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"Hammer Strut®" A New Efficient Earth Retaining Structure

— A simplified Angle Brace of Earth-Retaining Structure Reduces Cost —

Junichi HIRAO ► Senior Principal Engineer
Kaneyuki TAKANO ► Design Section Manager Civil Engineering Technology Division, Obayashi Corporation

Summary

Angle braces or blocks are installed in joints between struts and wall elements to support an earth retaining structure. Generally, assembling and dismantling of those members are time consuming because a large number of heavy members must be installed following a highly complex procedure. "Hammer Strut" employs general-purpose I-beams of the same size as the wall elements instead of angle braces. These I-beams are installed parallel to wall elements at the joints between the struts and wall elements. By doing so, the axial forces acting on the struts can be sufficiently dispersed.

Features

1) Lighter shoring system weight reduces lease costs.
- Substantial reduction in member weight, cutting lease costs of shoring system
- Only one-fourth to half of weight compared to angle pieces leased at temporary construction material providers, improving work efficiency
2) Shorter required time for assembling and dismantling of a shoring system.
- Reductions in member weights and the number of installed bolts, decreasing work time
- The position of the center of gravity getting closer to the wall, resulting in improved stability of the support during assembling and dismantling works
3) Larger openings allow easier construction of underground works.
- The absence of diagonal struts enabling to provide larger openings
Smoother loading and unloading of earth, sand, materials and equipment allowing underground excavation and construction work to be done more efficiently

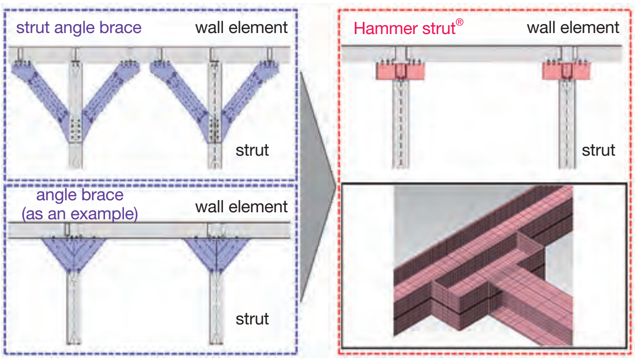

Fig. Comparing Hammer Strut (R) with a usual joint between a strut and wall element (L)

Photo An example Hammer strut

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Inventory Management System "Fair-Stock®"

Kengo SAITO ► Civil Engineering Sales Management Division Technology Solution Promoting Section FUJIMORI SANGYO CO.,LTD.

Background

The under-construction mountain tunnel in Japan, inventory management takes time and effort. That is usually carried out by young construction staffs in Japan. They couldn't recognize the shortage of materials because they don't know when and how many materials are used in construction process. It may cause the construction delays. As distributors of construction products, we needed to develop a system that is user-friendly and capable of preventing mistakes.

Summary of the System

To solve the problem, we have developed the system called "fair-stock®" (Fig.1). This system is designed to be user-friendly and mistakes-preventive for anyone utilizing it. It has convenient features for users (Fig.2). The features of this system are as follows:

1) This system facilitates easy inventory management through both PC and smartphone. This is cloud-based system, so it enables information sharing across multiple locations and related companies.

2) The system is designed to prevent mistakes by providing a calendar that is intuitive and easy to grasp the current status, and a simulation function that can predict future material usage.

3) It is possible to place an order for a fixed quantity or for the same quantity as in the past with a single click. This streamlines operations and contributes to increased productivity.

4) Since delivery slips are automatically output on the system, there is no need to print them on paper. This makes us to go paperless.

5) Actual material usage can be automatically calculated in the system by entering construction progress. By connecting to construction machinery, material usage can be obtained from the machinery and reflected in the inventory.

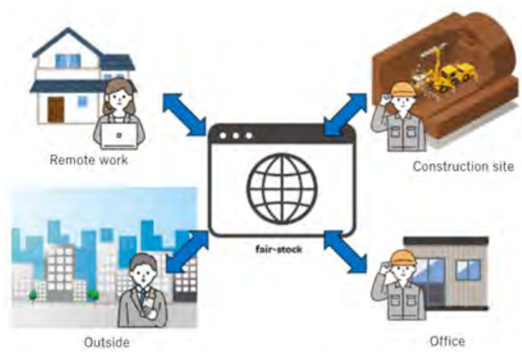

Fig.1 conceptual diagram

Fig.2 features of system

The Self-compacting Concrete Tunnel Lining System

Tomonori ONO ► General Manager, Civil Engineering Research Department, Technology Centre, Sato Kogyo Co., Ltd.
T.Ono@satokogyo.co.jp

1. Background

The construction of tunnel lining has some issues.
First, in terms of the social environment in Japan, the birthrate is declining, and the population is aging. Therefore, we are facing the problem of a shortage of skilled workers.
Next, in terms of the working environment for tunnel lining, compaction of concrete and shifting of concrete pipes are carried out in a very narrow space.
And in terms of quality, there is a possibility of concrete defects due to human error caused by the lack of skilled workers or by working in narrow spaces. Furthermore, in the conventional method, it is very difficult to prevent surface bubbles at the lower part of lining due to the difficulty of air releasing at the lower part of lining.

2. Developed System

With these backgrounds, we have developed a new construction method to improve productivity and to save manpower.
In this system, we place the self-compacting concrete through the injection hole installed at the bottom of tunnel lining formworks and fill it without compaction or shifting pipes.
We proved the usefulness and high completion of the system through the full-scale construction test conducted at the testing ground of Sato Kogyo Technology Centre. And we applied this new method to actual road tunnel construction project in 2023. Only three workers were needed to construct the tunnel lining. There were no segregation or unfilled areas. No surface air bubbles were observed.
This demonstration in actual project site proves the feasibility of improving productivity and manpower-saving for tunnel lining construction.

3. Outlook for the Future

To make this system general-purpose, we will continue to make the concrete low-carbon and low-cost and to improve the equipment and structure of the tunnel lining formworks, with the aim of fully automating tunnel lining in the future.

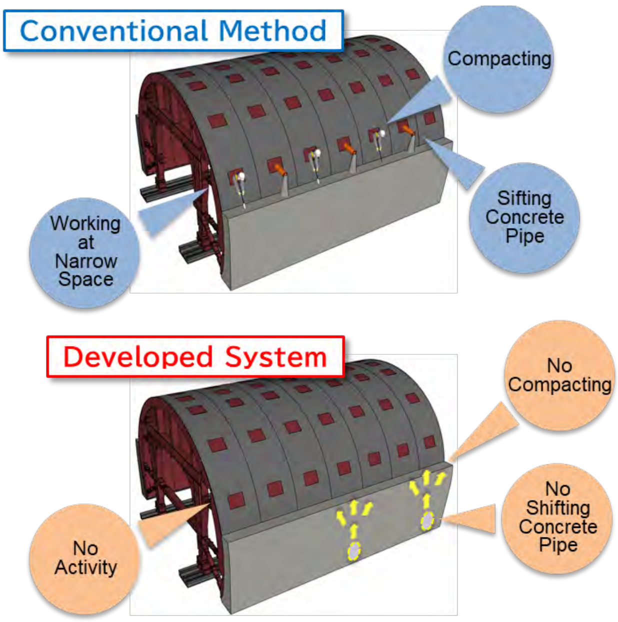

Fig. 1 Comparison of Conventional Method and Developed System

Automatic B-measuring System T- RIPPA BK Improved Safety and Productivity through LPWA Radio

TAISEI CORPORATION

T-RIPPA BK is a cable-free automatic B-measurement system for mountain tunnel construction, to evaluate the stability of surrounding ground and the design adequacy of support members (Figure 1). The acquired data is sent from a compact data logger (Fig. 2), which is capable of LPWA communication and requires no external power supply, to an LPWA receiver installed in the tunnel. The distance between the data logger and receiver can be separated by up to several hundred meters, and the data logger with a protective plate that does not block radio waves is installed in shotcrete, so it is not damaged by blasting. This is a highly productive system that eliminates the need for labor-intensive process of cable protection and blasting protection of the equipment.

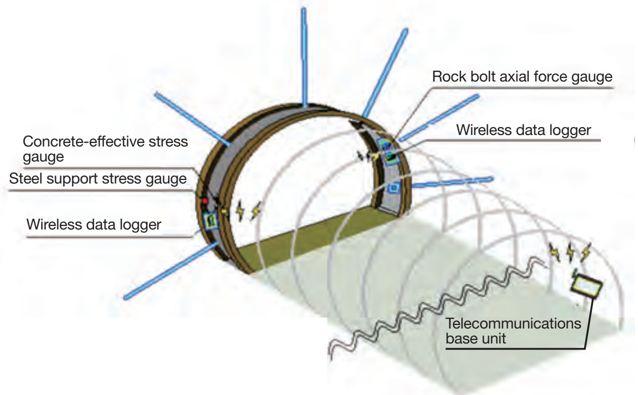

Fig. 1 Equipment configuration of T- RIPPA BK

Fig. 2 Data logger with LPWA

Fig. 3 Equipment installed

T-RIPPA BK is applicable at a level comparable in cost to B-measurement using conventional cables. The system also contributes greatly to the safety and productivity of B-measurement, with shorter installation time of the measuring equipment and considerable reduction of risks associated with working near the face.

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Roller Cutter Replacement System for Shield Machine "THESEUS Method®"

— Replace Roller Cutters Safely and Quickly by Robot Remote Operation —

TAISEI CORPORATION

A method to replace cutter bits of shield machines, "THESEUS Method®," is a system to enable replacement of roller cutters through remote robot operation within a shield machine. The development and application of this system enabled safe and quick replacement of roller cutters, which weighs several hundred kg per piece, without sending personnel to a narrow space. Figure 1 shows the configuration of this system. This system consists of (1) a roller cuter replacement robot, (2) roller cutter cases (inner case + front/rear outer cases, see Figure 2), (3) slide shutters (front shutter + rear shutter), (4) a movable manhole, and (5) a transport device.

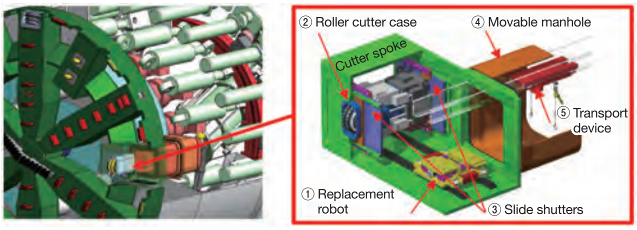

Fig. 1 Roller Cutter Replacement System to which THESEUS Method is Applied

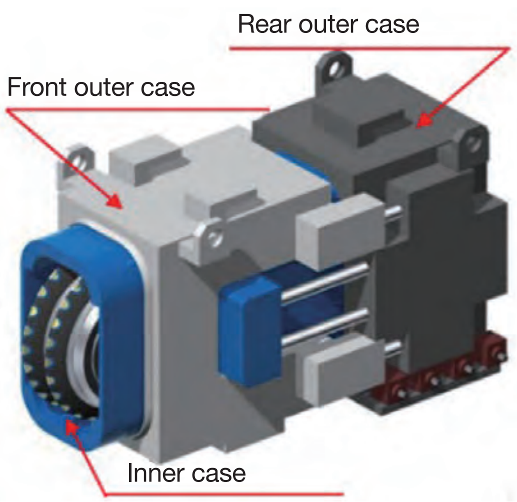

Fig. 2 Roller Cutter Case

In the future, this system will be applied to excavating of a gravel layer containing boulders, and in case that both rock bed and sandy soil ground are expected within the planned tunnel route, application of the THESEUS method will be expanded by using different cutter replacement systems depending on the ground.

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T-Shot Marker Face ˜Real-time Measurement of Shotcrete Thickness˜

TAISEI CORPORATION

"T-Shot Marker Face" is a system that measures the thickness of shotcrete on the face during concrete spraying work of a mountain tunneling work and displays the measurement results in real-time. It uses a 3D-LiDAR which can measure the shape of the face quickly and precisely to understand the shotcrete thickness. This product is capable of measuring 240,000 points per second and has a wide viewing angle. Therefore, even in a tunnel construction with a large cross-section, only single unit of 3D-LiDAR can be used to determine the shape of the entire face (Fig. 1).

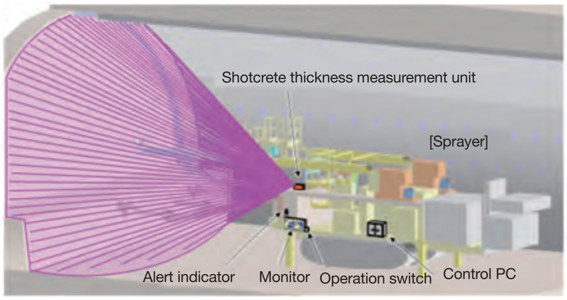

Fig. 1 Outline of Shotcrete Thickness Measurement by "T-Shot Marker Face"

The display of the result of measurement (Fig. 2) is updated to the latest data in every about 5 seconds. The point cloud data of the face is based on a high-precision measurement even under dusty environments with the aid of noise cut processing (Fig. 3).

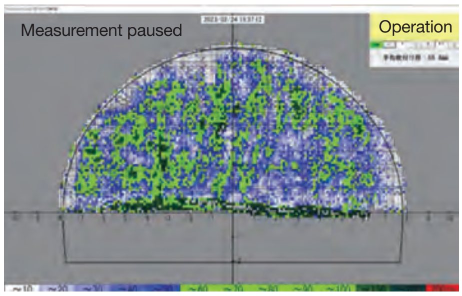

Fig. 2 Distribution of Shotcrete Thickness

Currently, this system is applied to mountain tunnelling projects in Japan, and improvements have been added in response to the site environment and construction conditions. In addition, development is underway to expand the scope of application of measurement to the outer circumferential side of the face, and this will be applied to automatic spraying technology to further improve construction efficiency and safety.

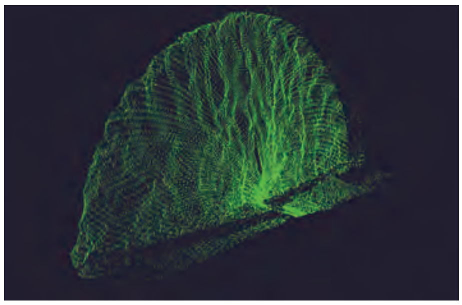

Fig. 3 Distribution of Shotcrete Thickness

Groundwater Forecasting® system for on-time groundwater environment prediction

Tsuyoshi FUKUDA ▶ Manager, Underground Work Division, Civil Engineering Technology Department, SHIMIZU CORPORATION

In the progressive adoption of BIM/CIM for mountain tunneling, a number of face-front investigations such as advanced boring or geophysical surveys have been performed. A 3D geological model can be created from those results for the area near and far from the face. Furthermore, predictive simulations can be done relatively easily by adding parameters (hydraulic conductivity, deformation coefficient, etc.) that represent the properties of the ground (strata) to this information

Groundwater Forecasting® uses a virtual drain model and estimates a groundwater environment on a daily and on-time basis through rapid 3D seepage analysis. Fig. 1 shows an overview of the Groundwater Forecasting® (Groundwater Prediction) system. The system consists of a 'real space (physical space)' and a 'virtual space (cyber space)' as a realization of the digital twin concept. In the real space, the system constantly acquires data of water inflows into the face and monitors total daily inflows. This information is stored in the cloud, and at the same time, fed to AI to identify the hydraulic conductivity of the ground for each observed water inflow. Using this identified hydraulic conductivity, a 3D seepage analysis can daily predict the amount of inflow that may occur in the near future. This enables prior detection of safety risks related to the groundwater, providing various benefits, such as the avoidance of work interruptions by implementing necessary proactive measures including auxiliary construction methods or additional drainage and sealing works.

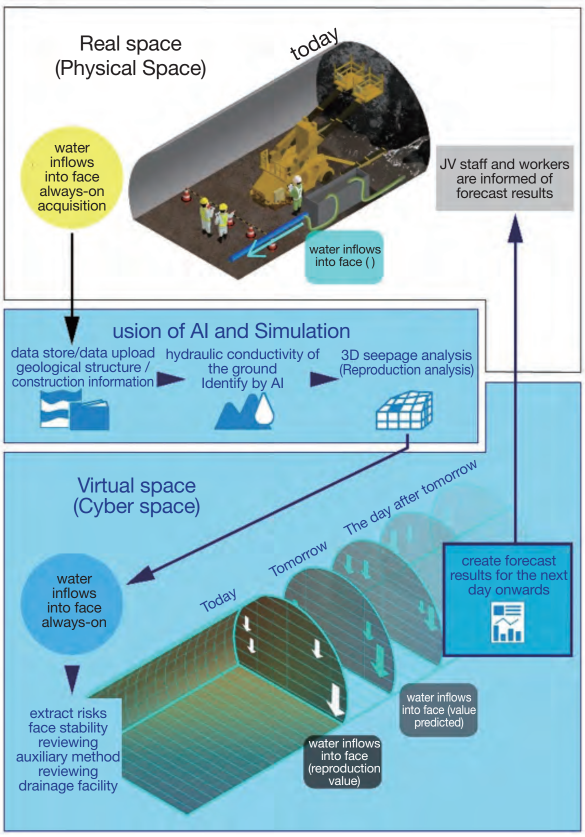

Fig. 1 Overview of Groundwater Forecasting (Prediction) System

Development of the Automatic Optimal Blasting Design and Construction System

Civil Engineering Technology Division, Tunnelling and Underground Space Engineering department, Shimizu Corporation
Kousuke KAKIMI ▶ General manager
Yasuo IDE ▶ Group manager

SHIMIZU CORPORATION, FURUKAWA ROCKDRILL CO., LTD. ENZAN KOUBOU CO.,LTD and JAPEX CORPORATION that jointly developed "The Automatic Optimal Blasting Design and Construction System", which automates and seamlessly links a series of operations from rock mass data acquisition to blasting design and drilling in blasting excavation of mountain tunnels(Figure 1).

This system automatically analyzes the geological conditions of the face in cyberspace based on the drilling energy values automatically collected by the fully automatic computer jumbo during the previous drilling cycle, and automatically creates the optimal blasting pattern according to the distribution of hardness and softness of the face. The blasting pattern is displayed on a zone diagram in which the face is divided into five sections, and the optimum number of holes and amount of charge are automatically assigned to each section (Figure 2). Next, the drilling plan corresponding to this created blasting pattern is imported into a fully automatic computer jumbo that can be programmed and controlled. The drilling plan is registered with the drilling sequence without boom interference based on the prior simulation of the drill jumbo boom flow line, thus realizing efficient automatic construction based on the optimum blasting design.

Application of the system resulted in a 69% reduction in the average amount of underbreak and a 41% reduction in the amount of overbreak associated with blasting drilling. The system also reduced the amount of explosives used by 7%. These effects not only significantly reduce cycle time and construction costs, but also improve the quality and durability of the tunnel by smoothing the tunnel excavation surface.

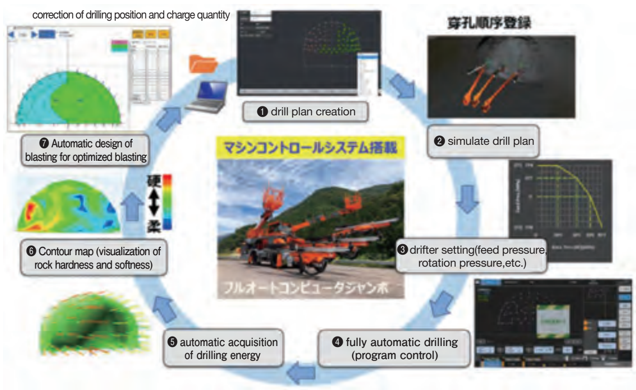

Fig. 1 Workflow of Automatic Blasting Design and Construction System for Optimized Blasting

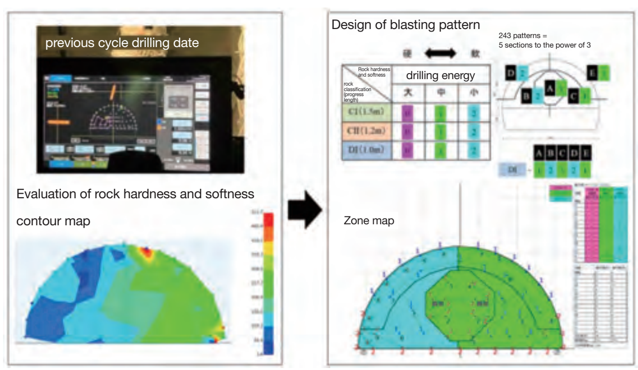

Fig. 2 Evaluation of rock hardness and softness and creation of blasting pattern

AI-aided Automatic Shield Machine Driving System

Tetsuya AOYAMA ► Civil Engineering Technology Division, SHIMIZU CORPORATION
Hirokazu SUGIYAMA ► Institute of Technology, SHIMIZU CORPORATION

Background

In shield construction, planning excavation instructions and operating shield machines require many years of experience and skills, as well as a great deal of effort. We have developed an AI-aided shield machine automatic operation system with the aim of reducing the labor involved in these works.

Summary

This technology mainly consists of a planning support system that creates a shield tunnel excavation plan and an operation support system that supports the operation of the shield machine. (Figure 1.)
The planning support system is equipped with a segment planning function that plans the arrangement of straight segments and tapered segments, and a function that determines the target alignment of shield machine excavation by considering the positional relationship between the shield machine and the segment ring. Furthermore, it has the function to create "excavation instructions" based on these results and hand it over to the operator or the operation support system.
The operation support system can instantly judge a huge amount of excavation information such as the current attitude and direction of the shield machine and select the appropriate jacks using AI that has learned how skilled operators operate the shield machine. (Figure 2.)

Achievements

These systems have been repeatedly tested and improved at a total of six sites, and we have now confirmed that highly accurate driving is possible. (Figure 3.)

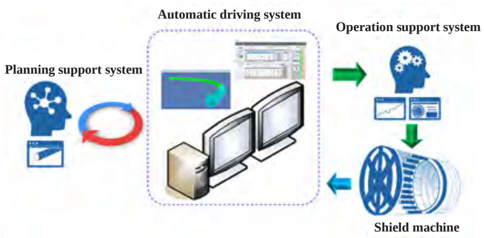

Fig. 1 Outline of automatic driving system

Fig. 2 User interface screen of automatic operation

Fig. 3 On-site verification of automatic operation

Members List

Public Corporations, Local Authorities, Owner Companies and Associations

Association of Nihon Tunnel Construction Sub-Contractors
http://www.tonnel.jp/index.html

Bureau of Sewerage Tokyo Metropolitan Government
https://www.gesui.metro.tokyo.lg.jp/english/index.html

Bureau of Transportatio, Tokyo Metropolitan Government
https://www.kotsu.metro.tokyo.jp/eng/

Central Japan Railway Company (JR Central)
https://global.jr-central.co.jp/en/

Central Nippon Expressway Company Limited
https://www.c-nexco.co.jp/en/corporate/

East Nippon Expressway Company Limited
https://www.e-nexco.co.jp/en/

Electric Power Development Co.,Ltd.
https://www.jpower.co.jp/english/

Express Highway Research Foundation of Japan
https://www.express-highway.or.jp/e/

HANSHIN EXPRESSWAY COMPANY LIMITED
https://hanshin-exp.co.jp/english/

Honshu-Shikoku Bridge Expressway Company Limited
https://www.jb-honshi.co.jp/english/

Japan Construction Machinery and Construction Association
https://jcmanet.or.jp/english/

JAPAN FEDERATION OF CONSTRUCTION CONTRACTORS
https://www.nikkenren.com/

Japan Railway Construction, Transport and Technology Agency (abbreviated name: JRTT)
https://www.jrtt.go.jp/english/

Japan Road Association
https://www.road.or.jp/english/

Japan Society of Civil Engineers
https://www.jsce-int.org/

Japan Water Agency
https://www.water.go.jp/honsya/honsya/english/index.html

Kyushu Electric Power Company, Incorporated
https://www.kyuden.co.jp/english_index.html

Metropolitan Expressway Co., Ltd
https://www.shutoko.co.jp/en/index/

Nippon Expressway Research Institute Company Limited
https://www.ri-nexco.co.jp/tabid/121/Default.aspx

NIPPON TELEGRAPH AND TELEPHONE CORPORATION
https://www.ntt.co.jp/index_e.html

Tokyo Metro Co., Ltd.
https://www.tokyometro.jp/en/index.html

TRANS-TOKYO BAY HIGHWAY CORPORATION
https://www.umihotaru.com/company/

West Nippon Expressway Company Limited
https://global.w-nexco.co.jp/en/

General Contractors

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https://www.aisawa.co.jp/

Aomi Construction Co., Ltd.
https://www.aomi.co.jp/en/

Arai Kensetsu.Co.,Ltd.
https://www.araikensetsu.co.jp/

AsunaroAoki
https://www.aaconst.co.jp/english/

DAIHO CORPORATION
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Dai Nippon Construction
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Fujita Corporation
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Fukuda Corporation
https://www.fkd.co.jp/company/

HAZAMA ANDO CORPORATION
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KABUKI CONSTRUCTION co.,ltd
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KAGATA CORPORATION
https://www.kagata.co.jp/

KAJIMA CORPORATION
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Kibe Kensetsu Co., Ltd.
https://kibekensetsu.com/

Konoike Construction Co., Ltd.
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MURAMOTO Corporation
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https://www.ohmoto.co.jp/index.html

Okumura Corporation
https://www.okumuragumi.co.jp/en/

Okumura Engineering Corporation
https://www.okumuradbk.co.jp/

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TEKKEN CORPORATION
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TENJO CORPORATION
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TOA CORPORATION
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TODA CORPORATION
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TOYO CONSTRUCTION CO.,LTD.
https://www.toyo-const.co.jp/en/

UEKI CORPORATION
https://www.uekigumi.co.jp/

UMEBAYASHI corporation
https://umebayashi.jp/company/company1/

WAKACHIKU CONSTRUCTION CO.,LTD.
https://www.wakachiku.co.jp/en/

YAMAZAKI Construction Co.,Ltd.
http://www.yamazaki.co.jp/index.html

Speciality Contractors

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http://www.daimaru-bouon.co.jp/

Hara Kogyo Co., Ltd.
https://harakogyo.co.jp/

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NOMURA CONSTRUCTION INDUSTRIAL Co.,Ltd.
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SEIWA RENEWAL CO.,LTD.
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http://www.yoshida-seihoh.co.jp/index.html

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Chiyoda Engineering Consultants Co., Ltd.
https://www.chiyoda-ec.co.jp/en/

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https://www.docon.jp/service

Eight-Japan Engineering Consultants Inc.
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Tokyo Metropolitan Sewerage Service Corporation
https://www.tgs-sw.co.jp/pdf/english202307.pdf

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https://www.epirocgroup.com/en

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Fujimori Sangyo Co., Ltd.
https://www.fujimori.co.jp/international/

Furukawa Rock Drill Co., Ltd.
https://www.furukawa-rockdrill.com/

FUSE CO., LTD.
http://www.fuse-ind.co.jp/index.html

GEOSTR Corporation
https://www.geostr.co.jp/

GIFU INDUSTRY CO., LTD.
https://www.gifukogyo.co.jp/en/index.html

HOKUETSU METAL CO., LTD
https://www.hokume.co.jp/

Hokuriku Steel Production Co., Ltd.
https://kenko-group.jp/kosan

H·R·O Co., Ltd.
https://h-r-o.net/

HYMO CORPORATION
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KYB Corporation
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MITSUI MIIKE MACHINERY CO., LTD.
https://www.mitsuimiike.co.jp/english/

Nikken Lease Kogyo Co., Ltd.
https://www.nrg.co.jp/nikkenlease/global/

NIPPO CORPORATION
https://nippo-tunnel.com

NIPPON CONCRETE INDUSTRIES CO., LTD.
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NIPPON STEEL CORPORATION
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OKUMURA MACHINERY CORPORATION
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https://www.master-builders-solutions.com/ja-jp

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https://www.seikenn.co.jp/

TAC Corporation
http://www.tac-co.com/en/

Taguchi Industrial Co., Ltd.
https://www.taguchi.co.jp/company

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https://www.taiheiyo-m.co.jp/english/

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https://www.taiyoweb.co.jp/

TOUKOU CORPORATION
https://www.k-toukou.jp/

TUZUKI CONCRETE INDUSTRY CORPORATION
http://tcic.co.jp/

Underground Infrastructure Technologies Corporation
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http://ynse.co.jp/

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